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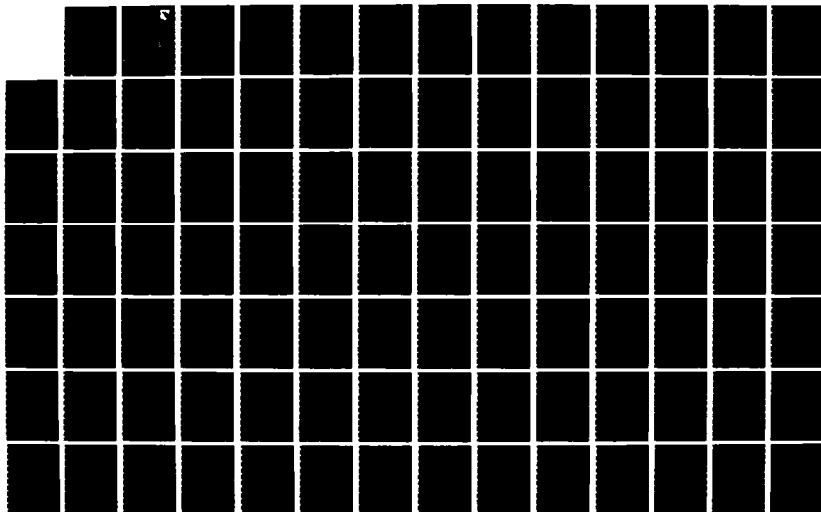
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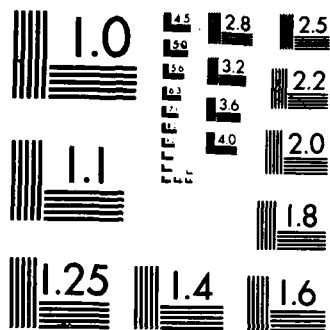
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**APPARENT MOTION AND PRIOR CORRESPONDENCE  
EFFECTS IN VISUAL PERCEPTION**

*ROBERT G. EGGLESTON*

*HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY*

*JUNE 1986*

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FOR THE COMMANDER



CHARLES BATES, JR.  
Director, Human Engineering Division  
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The process by which two visual stimuli presented at one time (t1) are paired with two different stimuli presented at a later time (t2) was investigated. Since there was more than one way for the stimuli to mate across frames, the task involved a problem in correspondence. It was proposed that the solution to a correspondence problem would be influenced (1) by the solution to the immediately preceding, or prior, one, and (2) by variations in the spatio-temporal characteristics of the sequentially presented apparent movement displays. When the prior and current correspondence problems were identical in structure, the influence of the former problem on the latter one was called a hysteresis effect; when the two problems were not identical in structure, the interaction between problems was called a priming effect. The results of eight experiments showed that (1) the hysteresis effect and priming effects were significant, and (2) the magnitude of both effects was related to the spatio-temporal parameters of the display sequence. In addition, both effects can operate in a telegraphic mode, can tolerate a difference in			
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the type of solution between the prior and current problems, and more recent correspondence problems have a larger prior correspondence effect than more frequent but less recent correspondence problems. ✓

A new psychophysical paradigm, called the Method of Interleaving Anchors (MIA), was developed in an effort to distinguish a prior correspondence effect from a response bias (error of habituation). The data support the interpretation that hysteresis and habituation probably are not the same phenomenon. Further, the MIA paradigm appears to be, in general, well suited to the investigation of different aspects of perceptual organization.



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## PREFACE

This report is a dissertation submitted to Miami University in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Experimental Psychology). The research was performed under the sponsorship of the Air Force Institute of Technology. Final preparation of the manuscript was completed with the support of the Human Engineering Division of the Harry G. Armstrong Aerospace Medical Research Laboratory.

Humans experience the world visually in terms of a connected series of complete (holistic) percepts. Each percept is formed without conscious effort and consists of an organized collection of objects and a background that together constitute a scene, as apprehended from a given cognitive perspective. It is known from everyday experience that scenes change constantly in any number of ways: for example, objects can move, change shape, be occluded by other objects, move relative to other objects and/or the background, or remain stationary. The processes by which stable visual percepts are formed from the complex dynamical interactions of the scene elements have been a major concern of experimental psychology ever since Wilhelm Wundt established the first laboratory devoted to an experimental analysis of human behavior at Leipzig, Germany in 1879.

Over the years, scientists have posted several theories to explain the fundamental nature of visual perception. These range from the notion that a percept is the unconscious product of mental reasoning to various approaches which rely on the synthesis of a percept from elemental sensations, elemental scene structure, or from "higher-order" invariances of scene content. In the past 10-15 years or so, much of experimental psychology has adopted an information processing model of behavior which subsumes perception but makes no attempt to clearly delineate it from sensation or cognition. From this framework, a visual percept is regarded as the product of one or more processes that are involved in transforming, analyzing, and synthesizing energy patterns impressed on the retina, and it may involve an interaction with knowledge stored in memory.

This report addresses the issues of how percepts are formed. It develops the concept of hysteresis, which is considered to be a fundamental property of the human visual information processing system. Percept formation is treated as a problem in determining the appropriate correspondence between objects presented over space and time. The solution of this problem is believed to be contingent upon the processing of data from the currently presented stimulus array and the infolding of relevant information stored in memory. It is this interaction that is described by the hysteresis phenomenon.

For dynamic scenes a continual stream of percepts must be formed, which means the correspondence problem is constantly being solved. Given knowledge of the operating characteristics of hysteresis and the spatio-temporal parameters of a scene, the form of a percept can be determined quantitatively.

Although the stimuli used in the research emphasize the use of motion information in the percept formation process, it is believed that the results are not limited to this situation, but rather pertain to visual percept formation in general. Some data supporting this position is contained in the report; however, additional research is needed to clarify the situation.

Applied researchers have been looking for many years for a way to describe and measure quantitatively human perception. There has been a strong tendency to concentrate on the development of techniques that measure performance in terms of stimulus properties that can be extracted from a scene directly. The present research suggests that such attempts will never be completely satisfactory, since information from this source alone is insufficient to resolve ambiguities contained in a time varying energy pattern impressed on the retina. Both the dynamic nature of visual information and the interaction of stored knowledge with new sensory data need to be considered in a description of visual perception. It is hoped that this research will stimulate other basic and applied scientists to develop new and more effective theories and analysis techniques of visual information processing which can be used to resolve person-machine interface issues in the design of complex systems.

I am indebted to many people who contributed to the successful completion of this work. It is a pleasure to acknowledge the encouragement given to me by Mr. Charles Bates, Director of the Human Engineering Division of the Armstrong Aerospace Medical Research Laboratory. Mr. Bates persuaded me to explore alternative avenues for obtaining an advanced degree after I had concluded that the "window of opportunity" for such a venture had passed. He also provided the atmosphere and time I needed to complete the writing of the final report. I also wish to acknowledge the guidance and support provided by my major professor, Dr. Allan Pantle. Besides sharing his knowledge of human perception and instruction in psychophysical research, Dr. Pantle suggested the 4-dot display used in the experiments. This display was crucial to the demonstration of perceptual hysteresis. Finally, I am grateful to Susan Albin, Sharon Seitz, and Brenda Taylor for preparation of portions of the manuscript, and to Ms. Sandra Stevenson for administrative assistance.

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## Chapter I

### PRIOR CORRESPONDENCE AS A HYSTERESIS EFFECT

Recently, the term "correspondence problem" has been used to describe the task the human visual system seemingly must perform to determine if an object has moved, changed form, moved and changed form, or remained stationary (Ullman, 1979; Anstis, 1980). The correspondence problem stems from the belief that the visual apprehension of the world occurs in a frame-by-frame manner. Each frame is composed of a large set of stimuli that may be said to constitute a "scene." Our awareness of a single "scene" can be regarded as a percept. When a series of frames follow each other in time, the entire scene and/or objects within the scene may appear to move and/or change form. The problem confronting the visual system is to determine how to match stimuli from one frame to the next. In other words, it must establish a correspondence between elemental stimuli as the entire set of stimuli varies over time.

The corresponding problem raises two separate issues about the processing of visually acquired information. The first is the problem of the definition of the stimulus involved in the matching process. The question here is, what corresponds? Do matches occur between globally defined objects, such as a person that moves and changes form over time? Or do they occur between attributes of objects, such as color, texture, or locally defined brightness levels? The second issue is concerned with the process by which matches are formed. Here the question is, how are individual partnerships between stimuli, however defined, determined? Since stimuli in successive frames can potentially be paired in several ways, the correspondence process must follow some

rules that restrict the pairings that actually materialize in the percept. What are these rules?

Research reported over the past several years has provided some insight into both of these questions about the nature of the correspondence process. It has been demonstrated, for example, that stimuli can be defined both in terms of a globally-defined (object) cue and in terms of a locally-defined (attribute) cue (Anstis, 1970; Pantle, 1973; Ramachandran et al., 1973; Braddick, 1973, 1974). Moreover, the spatio-temporal constraints on the correspondence process appear to be different depending on whether it is the global or the local cue that constitutes the relevant stimulus (Braddick, 1974; Pantle and Picciano, 1976; Petersik, Hicks, and Pantle, 1978; Petersik and Pantle, 1979; Pantle and Petersik, 1980). Thus, the what and how of the correspondence process seem to be at least partially interconnected. Further, because stimuli behave in a "global" and "local" manner at various times, perhaps even simultaneously, it is possible that there may be multiple levels of solutions to a correspondence problem.

It is proposed in this paper that there is an additional factor involved in the correspondence process. This is the factor of prior correspondence. Essentially, the issue is whether or not the result of one correspondence, say between stimuli on frames f1 and f2, is used to constrain a future correspondence, say between stimuli on frames f2 and f3. That is, will the f1-f2 matches influence in any way the matches that result between stimuli across frames f2 and f3? It will be shown that prior correspondence is an important characteristic of the correspondence process, and that its influence can be manifested in at least

two different forms. These will be referred to as a hysteresis effect and a priming effect, respectively. This chapter presents a discussion of the hysteresis effect. It includes a report of experiments that demonstrate the effect, relate it to the other aspects of the correspondence process, and address a paradigmatic problem related to its explanation. A discussion of the priming effect is presented in the next chapter. It includes a report of experiments that demonstrate the effect and show how it is affected by the manipulation of certain spatio-temporal parameters of a visual display.

#### A DEFINITION OF HYSTERESIS

The term hysteresis was originally used to describe the behavior of a magnetic substance as it is submitted to a continuously changing magnetic force. When a ferromagnetic metal, such as iron, is placed in a magnetic force field, the flux density of magnetism for that substance is altered relative to air; and the metal is said to be "magnetized." Change in flux density or, in other words, the "strength" of magnetism is related in a lawful manner to the intensity of the magnetic force. An idealized form of this relationship is shown in Figure 1. Changes in both strength and polarity of induced magnetism occur as a function of the degree and polarity of the magnetic force. Initially, the ferromagnetic substance is not magnetized (i.e., the flux density in the material is the same as that in air). This point is designated by the letter O at the origin of the graph. As the magnetic force (H) is increased (positive polarity), flux density in the material increases until a point of saturation (A) is reached. Further increases in magnetic force will not increase the strength of magnetism beyond the

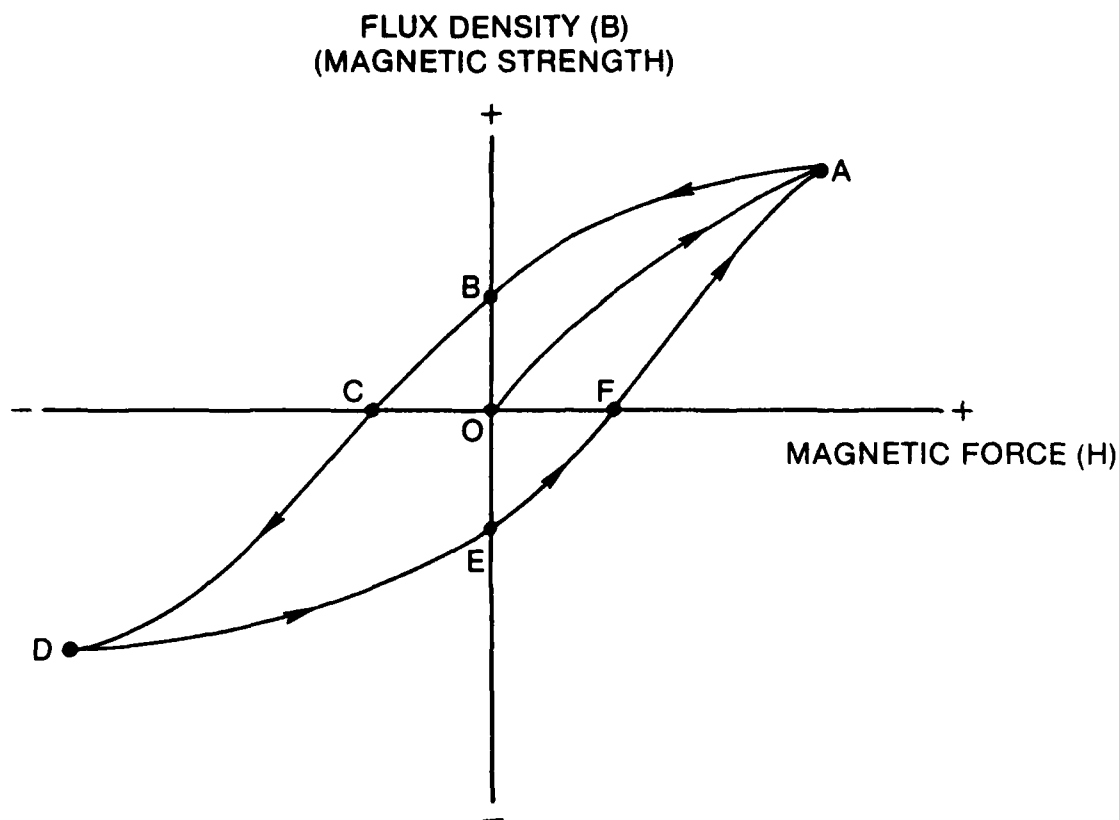


Figure 1. Relationship Between Magnetic Force (H) and Flux Density (B) (The characteristic curves indicate how changes in flux density lag causal changes in magnetic force. The combined curves are known as a hysteresis loop.)

saturation point. Now, consider what happens to the extent of magnetism as the magnetic force is reduced to zero. As expected, magnetic strength falls off, but note that when the magnetic force is at zero strength, some magnetism remains in the ferromagnetic substances (point B). That is, the magnetic flux density does not return to zero, even though an initially unmagnetized piece of iron would show no magnetism at the same level of magnetic force. After the polarity of H is changed, a point (C) is reached where the iron is returned to an

unmagnetized condition. Further increases (absolute value) in  $H$  result in an increase in magnetism (reverse polarity), again until saturation (point D) is reached. As before, when  $H$  is returned to zero, the iron substance remains magnetized (point E), and shows the same lag of effect behind cause as previously described, but with reverse polarity.

Hysteresis, then, is a state wherein there is a lag in an effect behind associated changes in the cause. When such a lag occurs dynamically between two saturation levels of opposite polarity, the situation is characterized by a loop structure as shown in the figure. This is known as a hysteresis loop.

#### HYSTERESIS AND THE CORRESPONDENCE PROBLEM

At first, it may be difficult to envision the connection between the concept of hysteresis and the correspondence problem in visual perception. The connection is perhaps best acquired by way of a simple illustration. Three individual frames of a display that each contain two dots are shown in Figure 2. The frames are presented, one at a time, in sequence beginning with  $f_1$  at  $t_1$ . For this display, the correspondence problem is limited to the determination of which of two possible partner arrangements will occur. That is, will the dots pair along the lines of the solid arrows or the dashed arrows? Let us assume that correspondence has followed the solid arrows across frames  $f_1$  and  $f_2$ . At this point in time, a new correspondence problem must be solved for frames  $f_2$  and  $f_3$ . As before, the same two alternatives exist. How will the correspondence problem be resolved this time? If the partnerships established over the  $t_2, t_3$  interval (frames  $f_2$  and  $f_3$ ) are formed independently from those formed over any other increment of time, namely

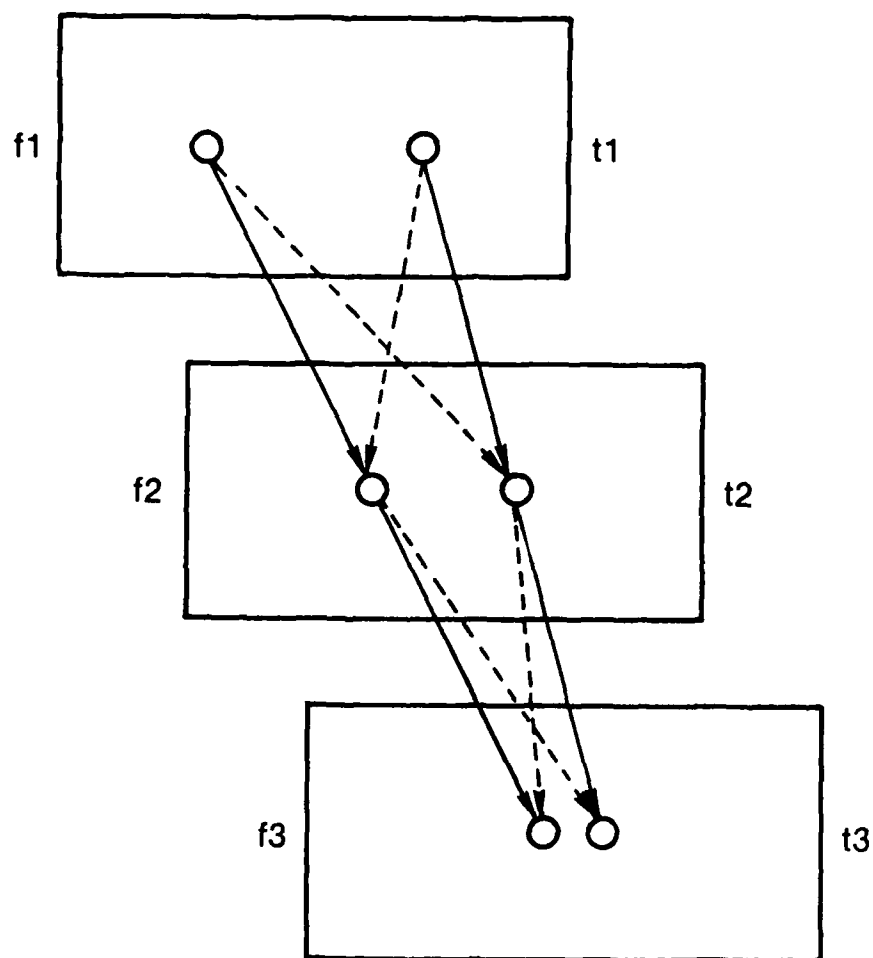


Figure 2. Two Possible Stimuli Pairings Across Three Successive Frames (f1-f3) of a Dynamic Visual Display

$t_1$ - $t_2$ , then there would be an equal probability of the dots swapping their former mate as there would be of retaining their old mate. If a hysteresis effect is operative, however, then there would be a reluctance to release the old mate to establish a new dot pair. Therefore, given a hysteresis effect, the expected value of the partnership established over the  $t_1, t_2$  interval would be greater than the expected value of the alternative partnership for the  $t_2, t_3$  interval. Thus, the hysteresis effect reflects a condition wherein prior correspondence constrains the correspondence process at the next point in time.

To test for a hysteresis effect in the correspondence process, at least three conditions must be met. As a minimum, one needs: (1) a dynamically changing stimulus pattern that can induce at least two different percepts, (2) a display that, under some circumstances, can be stabilized to yield only a single percept, and (3) a means of manipulating the display so that the likelihood that a particular percept will be induced can be systematically changed over a series of trials.

When suitable adjustments are made, the 4-dot dynamic display shown in Figure 3 will satisfy the first two conditions. The two dots in Figure 3 labelled A and C, respectively, are both presented at the same time-- $t_1$ . The remaining two dots, B and D, are presented at time  $t_2$ . The numbers inside each dot correspond to both the frame number and the time period each dot is exposed to the observer. (This notation will be used in all following figures.) If suitable timing is used, the dots on frame  $f_1$  can be made to appear to move to the dots on  $f_2$ . This type of motion is called apparent movement (AM), and it has been known to exist since the late nineteenth century (Wertheimer, 1912). Although there is

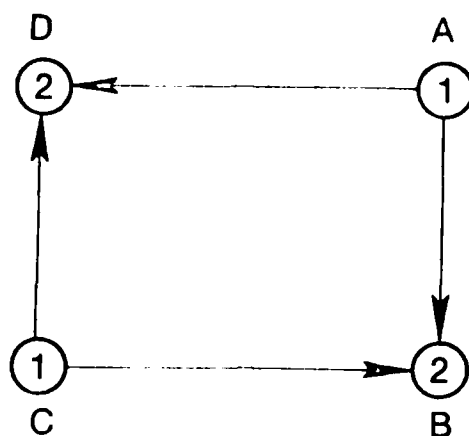


Figure 3. 4-Dot Dynamic Display

no physical motion in this display, the impression of motion that it can produce is quite compelling, provided the temporal display parameters are well chosen (see Kolers, 1972). As the arrows in the figure suggest, there are two different ways the dots of  $f_1$  can mate with those on  $f_2$ . Each of these produces AM along a different path. If the A, D and B, C partnerships form, then the resultant percept would be one of two dots moving vertically. One would appear to move downward while the other moved upward. Hereafter, this AM percept will be called vertical apparent motion (VAM). Alternatively, if the A, B and C, D partnerships form, then the resultant percept would be dot movement (AM) in opposite directions along a horizontal meridian. Hereafter, this AM percept will be called horizontal apparent motion (HAM).

A third potential solution to the correspondence problem is not shown in Figure 3. Either or both dots of  $f_1$  could split and mate with both dots of  $f_2$ . Although these possibilities exist theoretically, in actual fact they only rarely occur. Therefore, for all practical

purposes, the correspondence problem is reduced to a choice between two different dot pairings with the 4-dot display. Thus, the partnerships that are actually formed over any adjacent time intervals (e.g.,  $t_1, t_2$ ) are revealed by the direction of the path of motion the observer experiences; and the apparent direction of motion indicates the solution chosen by the visual system for the correspondence problem posed by the 4-dot display.

Pilot work has shown that a simple spatial manipulation can be used to alter the 4-dot display such that it will seemingly always induce a single percept. There exists a horizontal separation between dots, for example, that appears to always induce a vertical AM (VAM) percept. Similarly, there exists a second horizontal separation between dots that appears to always induce a horizontal AM (HAM) percept. These stretched and compressed versions of the 4-dot display are shown in Figure 4. Although both of these versions of the 4-dot display induce a stable percept, it is important to remember that each of these displays theoretically admits of at least two solutions to the correspondence problem. The nonpreferred solution is, in each case, indicated in Figure 4 by dashed arrows. Since the nonpreferred solutions apparently never occur when the 4-dot display is suitably stretched or compressed, but they do occur at other times, this general display configuration satisfies the first two conditions needed to demonstrate hysteresis in the correspondence process.

It should be apparent that hysteresis would go undetected in the study of magnetism if magnetic force were changed discretely and abruptly between those magnitudes which yield a saturated level of

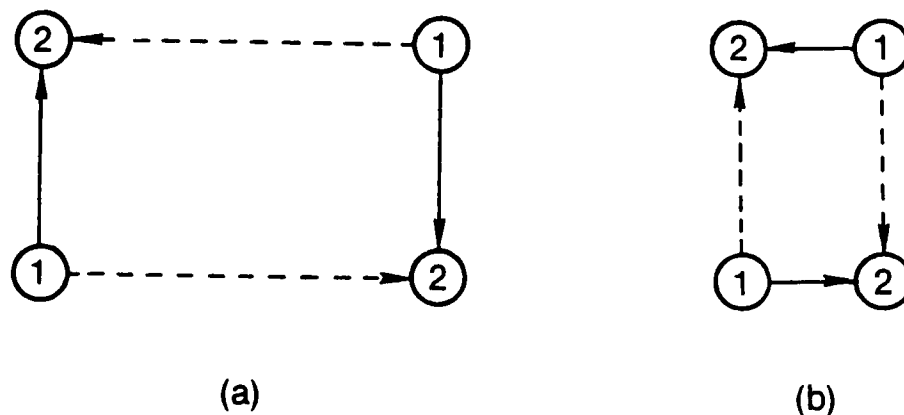


Figure 4. Stretched (a) and Compressed (b)  
Versions of the 4-Dot Display

magnetic strength (see points A and D on Figure 1). The magnetic substance would be seen as simply changing its polarity, and the underlying structure of the relationship between flux density (strength) and magnetic force would not be manifest.

In order to appreciate the functional relationship between magnetic force and magnetic strength (i.e., observe the hysteresis effect), it is necessary to measure magnetic strength at several levels of force between the two saturation points. Furthermore, the magnitude of force must be varied in a gradual, step-wise manner throughout the unsaturated region. This is the reason for the third and final condition that must be met if a hysteresis effect is to be detected in the correspondence process in visual perception. Fortunately, this condition can be satisfied by the use of the psychophysical method known as the Method of Limits (Kling and Riggs, 1972).

## EXPERIMENT I

This experiment provides an initial demonstration of the hysteresis effect as a characteristic of the correspondence process in visual perception. The demonstration involves the manipulation of the horizontal displacement between dots in the 4-dot display in accordance with the Method of Limits (M of L) paradigm. The hysteresis hypothesis states that a given solution to the correspondence will resist change. In the present context, there are only two solutions available to the correspondence problem, either a HAM percept or a VAM percept. Therefore, it is expected that an initially formed VAM percept (stretched display) will resist change to a HAM percept until the display is compressed to a large degree (descending series of M of L). Similarly, an initially formed HAM percept (compressed display) is expected to resist change to a VAM percept until the horizontal separation is quite large (ascending series of M of L). If the underlying relationship between the strength of a percept and the horizontal separation of dots in the dynamic 4-dot display involves hysteresis, the points of transition between the VAM and HAM percepts would be expected to occur at different values of horizontal dot separation for the ascending and descending series. A significant difference in the VAM-to-HAM and HAM-to-VAM transition points, in the appropriate direction, will be taken as evidence in support of the hysteresis hypothesis. All other results will constitute nonsupport for the hypothesis.

## Method

### Subject

Twelve undergraduate college students served as subjects to satisfy a research participation requirement. All subjects had normal vision, either with or without the use of eyeglasses or contact lenses. Subjects with optical corrections had received an eye exam within the past two years. All subjects were untrained as psychophysical observers, and they were naive with respect to the purpose of the experiment.

### Apparatus

The main experimental equipment consisted of a Radio Shack TRS-80 Color Computer™ interfaced with a standard 13-inch RCA color television, a Radio Shack line printer (Model VII), and a joystick/fire control box. All visual displays used in the experiment were generated by the computer with locally developed software, converted to appropriate analog signals by the computer hardware, and presented on the color CRT monitor. A detailed description of the basic training and experimental displays, as well as a fixation target, follows.

Training Display (TD). The TD contained four different frames, three with two stimulus elements and one with a uniform blank field. For ease of description, the three stimulus frames will be labelled A, B, C (see Figures 5a through 5g), and the blank frame will be treated as an interframe interval (IFI). The frames of the display were presented in the following temporal order: A, IFI, B, IFI, C. Thus, there was a

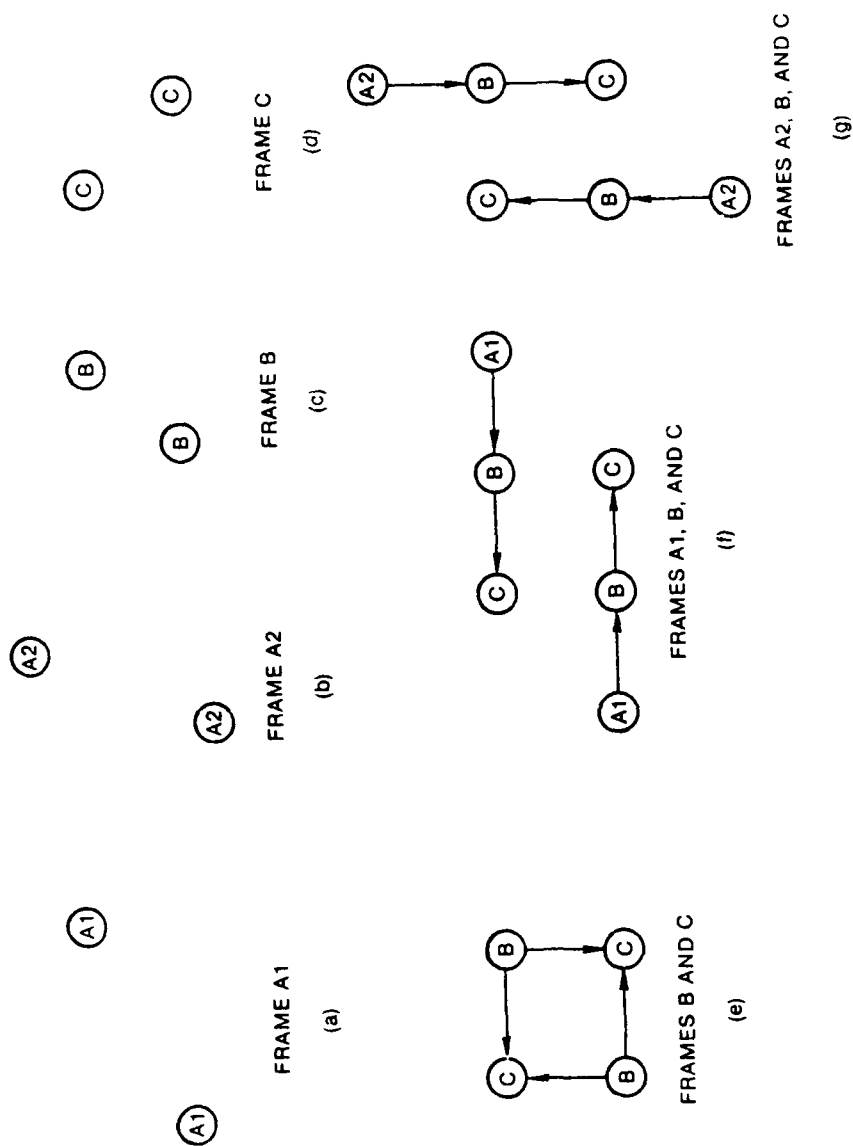


Figure 5. Single Frame and Composite Frame (Collapsed Over Time) Illustrations of the Training Displays Used in Experiments I through VIII

blank frame between each stimulus frame presentation. The stimulus elements on frames B and C together constitute a 4-dot display, as previously discussed (see Figure 5e).<sup>1</sup>

Two separate target configurations were used on the first frame of the TD display (frame A). Frame A1 contained a pair of stimuli positioned laterally away from the target elements on frame B (see Figures 5a and c). The pair of stimuli in frame A2 were vertically displaced away from the elements on frame B (see Figures 5b and c).

All the stimuli in the training display were green luminous plus (+) signs. The vertical segment of the plus sign subtended 12 arc minutes of visual angle; the horizontal segment, 8 arc minutes of visual angle. The background on all target frames, as well as the IFI frame, consisted of a uniform black field. Each target frame was displayed for approximately 185.5 milliseconds. All blank frame presentations lasted approximately 31.17 milliseconds. Given the stated sequence and timing parameters, one cycle through the frames in the prescribed order produced an apparent motion display. When frame A1 was used to initiate the sequence, the series of plus signs appeared to move in opposite

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<sup>1</sup>The color television is a raster scan device. This means that, technically speaking, no two points on the television screen are illuminated precisely at the same time. Since it takes only 63.5 microseconds for the raster to scan one horizontal line, separate stimuli on a line can be considered to occur simultaneously. It takes 16.67 milliseconds to scan the entire screen surface and, therefore, vertically displaced targets are not presented at the same time. The maximum time interval between the imaging of two dots on any single frame (e.g., B, C) used in this study was 1.5 milliseconds since the vertical distance between dots was set at 24 raster lines. This delay is well below the threshold for successiveness (Happ, 1982); therefore, the dots can be considered to occur simultaneously.

directions along two separate but parallel horizontal motion paths (see Figure 5f). Employing frame A2 instead of frame A1 in the display, a similar motion pattern emerged, except that the apparent motion tracks were oriented vertically (see Figure 5g). Thus, a single presentation of the TD activated a shearing motion percept, but the orientation of the motion paths, vertical or horizontal, differed depending upon whether frame A1 or A2 was used in the display sequence.

Experimental Display (ED). The ED display contained stimulus elements in a configuration identical to that shown in frames B and C of the TD. That is, they formed the basic 4-dot display. Here, too, the target frames were separated by a blank frame; therefore, the display sequence was B, IFI, C (see Figure 5e). Target frame duration was approximately 185.5 milliseconds, and the IFI frame duration was approximately 31.17 milliseconds.<sup>2</sup> Each stimulus element was a green luminous square (6.8 footlamberts) that subtended 4 arc minutes of visual angle. The vertical separation (center-to-center) between stimuli of frames B and C was 48 arc minutes of visual angle. Between frame horizontal separation of the stimuli changed from trial to trial (in the range of 116 to 8 arc minutes) in accordance with the Method of Limits procedure.

<sup>2</sup>The technical data accompanying the TSR-80 Color Computer™ provided no information regarding synchronization of the computer video signal output to the television raster scan circuitry. Consequently, even though display timing was set precisely at 200 milliseconds and 16 milliseconds for frame duration and IFI, respectively, by a machine language software routine, actual presentation time was different because this routine was not synchronized to the raster scan and because the dots did not fill the entire screen. Moreover, there was a 9 percent chance that the raster scan would begin at a point between the two dots on a display frame on each trial.

Fixation Target (FT). The FT is shown in Figure 6. All four fiducial marks were 16 arc minutes in length and positioned outside of the region of the screen used for target stimuli. The fiducial marks were located along the major and minor axes of an ellipse centered on the TV screen. The inside distance between opposing marks was 4.27 and 4.00 degrees of visual angle in the horizontal and vertical directions, respectively. The subject was instructed to fixate the point of intersection of the two imaginary lines that extended through each pair of fiducial marks. The stimulus elements contained in each ED display were centered about the fixation point. The FT and ED displays were never presented at the same time.

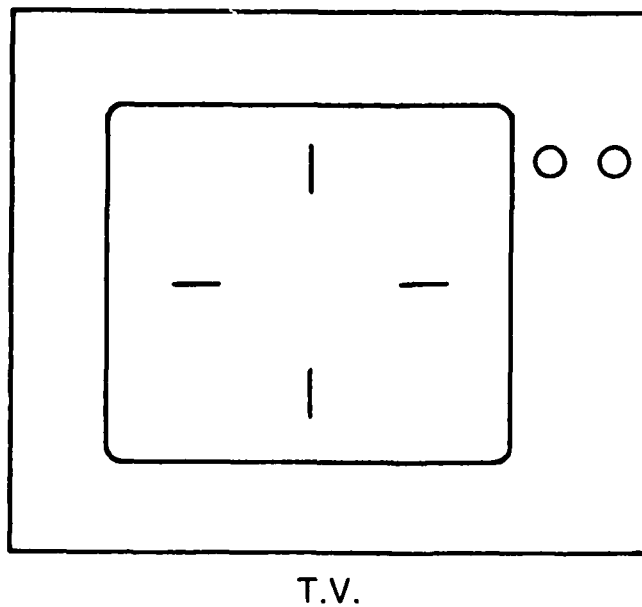


Figure 6. Fixation Target for Experiments I through VIII

Subject Station. This station consisted primarily of the color monitor and the joystick/fire control box. The monitor was situated on

top of a table such that the center of the viewing area was 120 cm above the floor. A cardboard mask with a 5.75 degree by 5.75 degree (visual angle) aperture centered on the monitor screen was placed over the face of the monitor. The mask occluded a green border around the active display area. Since the mask was not contoured to conform to the curvature of the screen, some green color light emitted by the border was reflected off the inner surface of the mask and back onto the graphics display area. The resulting pale green penumbra was highly diffused and restricted to the extreme margins of the screen. It did not intrude into the active display area where the experimental stimuli were presented.

The subject viewed all displays while seated in an armchair which was located such that the eye distance to the monitor was approximately 153 cm ( $\pm 2.56$  cm). The subject held the joystick/fire control box in his hand throughout the experiment. The fire control button was used to initiate a display sequence. The joystick was used to record the type of AM percept experienced--either VAM or HAM.

Experimenter Station. This station contained the microcomputer keyboard, a computer mass storage device, and a printer. It was physically adjacent to the subject station, but separated from it by a cardboard partition. Programs consisting of the display generation and response recording routines were loaded into the computer prior to the beginning of the experiment and executed at appropriate times throughout the experiment. Each AM response of the subject was recorded by the computer. A hard copy printout was made of only those responses that

reflected a change in the AM percept from the immediately preceding trial.

Room illumination was provided by a 7.5 watt incandescent light located at the experimenter's station. The lamp was appropriately baffled to avoid any specular glare on the face of the monitor.

The luminance of each stimulus on the monitor was approximately 6.8 ft-L. Background luminance was approximately 0.008 ft-L.

#### Procedure

Each subject participated in one experimental session which lasted approximately 60 minutes. The session was divided into two parts: training/familiarization and experimental. The procedure followed in each of these phases of the experiment is described below.

Training/Familiarization. The purpose of the training/familiarization phase was threefold: (1) to familiarize the subject with the general types of apparent motion they would perceive in the experimental phase, (2) to avoid the imposition of an instructional set that might bias their perception of the display, and (3) to allow time for the subjects to adapt to the ambient illumination used in the experimental phase.

A trial in this phase consisted of a sequence of four events. First, a uniform dark field was shown. This was followed by the 3-frame TD sequence. Next, a circular target appeared on the screen. The purpose of this target was to cue the subject when to respond. This prompt was located outside of the active target area of the display and was not

imaged until 1 second after the completion of the TD. This delay was needed to insure that there would be no apparent motion between the TD and the prompt. Finally, the blank field was reintroduced to preserve the subject's adaptation state.

The trial sequence was explained to the subject who was told to report verbally the type of motion perceived in the TD after the prompt had terminated. No other information regarding the TD was given. After the subject was instructed to maintain a "passive stare" at the center of the screen, a TD containing frame A2 was presented. All subjects reported perceiving vertical motion or the counterclockwise rotation of an imaginary rod whose end points were defined by the stimulus elements. The same display was presented again. Those subjects who used the rotating rod description were asked to use different terms to characterize the motion this time. All of these subjects now described the motion as vertical. An identical procedure was followed with frame A1 in the TD. All subjects reported perceiving horizontal motion, although some initially described it in terms of a clockwise rotation of an imaginary rod. Each version of the TD was presented three more times to allow the subject to form a mental image of the vertical (VAM) and horizontal (HAM) percepts. This concluded the familiarization portion of the training/familiarization phase.

Training continued with eight additional presentations of the TD. Frames A1 and A2 were randomly selected for inclusion in the TD, with the constraint that each frame had to be used four times. When frame A1 was used, all subjects reported a HAM percept. Conversely, with frame A2 in the TD, they always reported a VAM percept.

Experimental Phase: Method of Limits Procedure. In this phase, two versions of the 4-dot test display (4D) were used. These displays differed only in terms of the vertical separation between stimuli. This separation was set at 48 arc minutes for one display and 32 arc minutes for the other. Hereafter, these versions of the 4-dot display will be identified as 48V and 32V, respectively. The subject's task was to indicate whether the 4-dot display induced a vertical AM percept or a horizontal AM percept, similar to those that emerged with the TD display. The joystick/fire control box was used to register responses. All display presentations were initiated by the subject (self-paced) by depressing the fire control button on the joystick apparatus.

The sequence of events on each trial was identical to that used in the training/familiarization phase, except that it commenced with the fixation target. In short, the visual presentations on each trial were, in order: fixation target--blank field--4-dot display--blank field--response prompt--blank field. The purpose of the two blank fields surrounding the target display was to prevent any apparent motion between either the fixation target or the response prompt and the stimulus elements of the ED.

Trial presentations were made in accordance with a ML paradigm. The procedure always began with a descending series of trials. The horizontal separation between stimuli in the 48V display was initially set at random between 116 and 104 arc minutes for these trials. This range was changed to 76-64 arc minutes when the 32V display was used. The horizontal separation between stimuli of the 4-dot display was incrementally reduced by 4 arc minutes (center-to-center distance) from

trial to trial until a HAM percept response was made on two consecutive presentations. Then, an ascending series of trials was initiated. Horizontal separation was preset at random between 4 and 16 minutes arc for both the 48V and 32V displays for the ascending series. This separation was incrementally increased at the 4 arc minute rate between trials until two consecutive VAM responses were made. All preset horizontal separations were selected on the basis of pilot research. It was found that these separations induced initial stable AM percepts of the desired form.

The entire experiment consisted of an alteration of six ascending and descending trial sequences. The 48V display was used for one block of three alternating ascending and descending sequences, and the 32V display was used during the remaining trials. The order of presentation of the blocks was counterbalanced across subjects.

Since the subjects had not used the joystick response apparatus during training/familiarization, a short practice session was provided prior to data collection. Typically, 10 to 15 practice trials were needed to ensure reliable use of the response equipment.

### Design

The experimental plan conformed to a 2 x 2 factorial design. One factor was the vertical separation of elements of the 4-dot display. There were two levels of this display factor--48V and 32V. The remaining factor was the order in which successive trials were presented to the subject. They were two levels of the order factor--ascending and descending sequences.

## Results and Discussion

A percept transition point (PTP) was calculated for each ascending and descending series of trials. The PTP is defined as the horizontal separation between elements of the 4-dot display that existed when one AM percept was exchanged for another (i.e., VAM to HAM or vice versa). For ascending trials, the PTP was taken to be the horizontal separation (in arc minutes of visual angle) at the time the first of two consecutive VAM responses was recorded minus 2 arc minutes. For descending trials, the PTP was taken to be the horizontal separation at the first of two consecutive HAM responses plus 2 arc minutes. The 2 arc minute correction factor was applied to set the PTP at the midpoint of the 4 arc minute step size used in the experiment.

The PTP data were analyzed separately for the 48V and 32V displays. A separate mean PTP score was found for ascending and descending trials for each subject. These means, based on three measures, are presented in Table 1 for the 48V and 32V display conditions. Subjects 1 through 6 were tested with the 48V display first. The remaining subjects (7 through 12) were tested in reverse order. A preliminary analysis was performed to determine whether order of presentation affected the PTPs. Using mean subject PTP data, separate t-tests were performed for the ascending and descending series. In each instance, the t value was less than 1.0, and statistically not significant.

The data from all subjects were pooled to form group mean PTP values. These group values are provided as marginal means in Table 1. All further analysis was based on these mean data, since the pattern of

TABLE 1. MEAN HAM TO VAM (ASCENDING TRIALS) AND VAM TO HAM (DESCENDING TRIALS) PERCEPT TRANSITION POINTS BY SUBJECTS

48V			32V		
Subject	$\bar{X}$ ASC	$\bar{X}$ DSC	Subject	$\bar{X}$ ASC	$\bar{X}$ DSC
1	42	18	1	28	16
2	46	20	2	32	24
3	56	28	3	40	22
4	62	34	4	38	24
5	44	26	5	34	22
6	42	34	6	32	22
7	42	30	7	28	20
8	34	22	8	28	22
9	50	40	9	36	18
10	53	42	10	28	26
11	50	34	11	46	22
12	52	34	12	32	20
Mean	47.75	30.17		33.5	21.5
SD	7.58	7.60		5.66	2.71

results was essentially the same across all subjects. For the 48V display, the descending series PTP mean (i.e., VAM to HAM transition) was 30.17 arc minutes and the ascending series PTP mean was 47.75 arc minutes. The descending and ascending mean PTP values were 21.5 and 33.5 arc minutes for the 32V display. Both of these results agree with the hysteresis hypothesis. That is, the HAM to VAM transition clearly did not occur at the same point as the VAM to HAM transition when either the 48V or 32V display was used. A 2 x 2 factorial analysis of variance with repeated measures confirmed this observation. Both the Trial Order (ascending versus descending) factor and the Display (48V versus 32V)

factor were significant [ $F(1,11) = 116.80$ , and  $F(1,11) = 69.33$ ,  $p < .001$ , respectively]. The Trial Order by Display interaction failed to reach significance at the .05 level of confidence [ $F(1,11) = 4.27$ ,  $p < .10$ ]. A summary of the results is provided in Table 2 and shown graphically in Figure 7.

TABLE 2. SUMMARY OF ANOVA EXPERIMENT I

Source	SS	df	MS	F
Trial Order (TO)	2800.82408	1	2800.82408	116.07*
Subject	871.650513	11	79.24096	
TO x Subject	265.440384	1	24.130944	
Display (D)	1526.18411	1	1526.18411	69.33*
D x Subject	242.151443	11	22.0137676	
TO x D	68.5451965	1	68.5451965	4.27
TO x D x Subject	176.559464	11	16.0508603	
TOTAL	5951.3552	47		

\* $p < .001$

The hysteresis hypothesis states that the HAM to VAM (H-V) PTP should occur at a large horizontal separation between display elements, since the initial HAM percept will resist changing to a VAM percept. Conversely, the VAM to HAM (V-H) PTP should occur at a small horizontal separation for a similar reason. It can be seen from Figure 7 that these relationships held in this experiment for both the 48V and 32V displays. If these relationships had been reversed, and the calculated  $F$  ratios significant, the data would no longer support the hysteresis

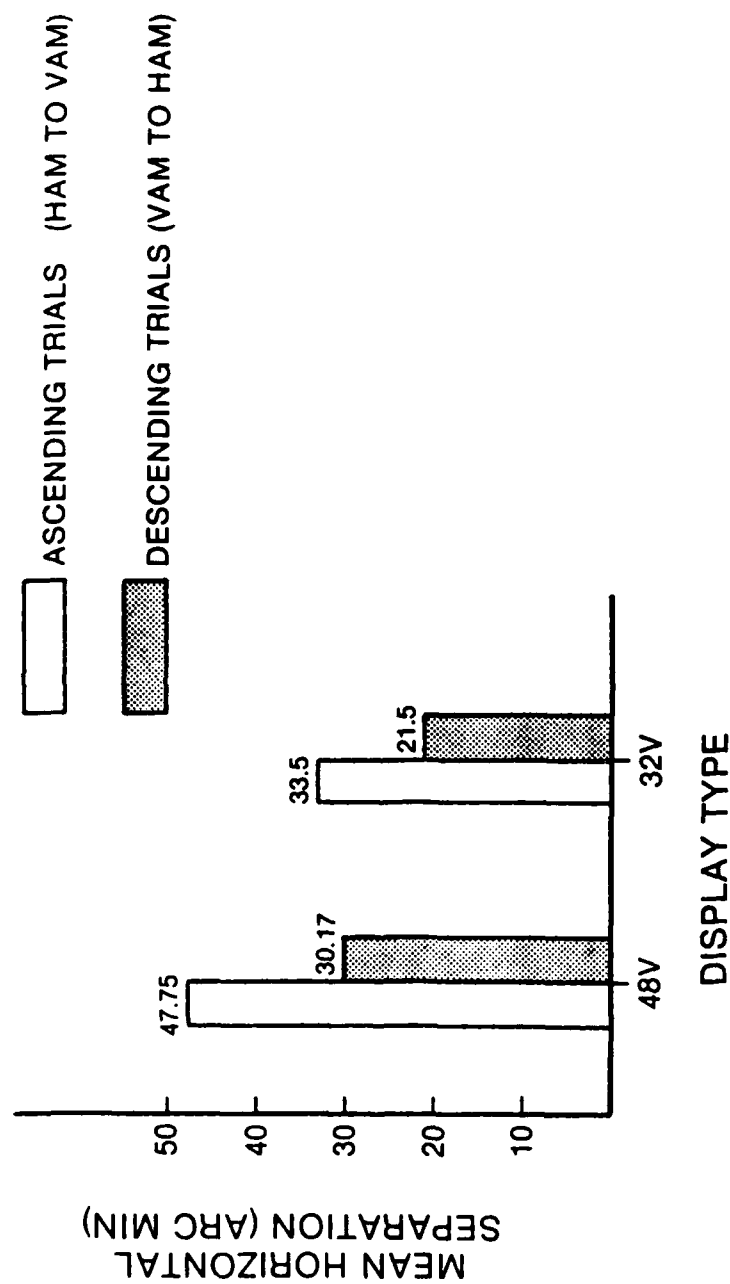


Figure 7. Mean Horizontal Dot Separation for Ascending and Descending Trial Orders by Display Type

effect, since the PTPs would suggest a strong readiness to change from a prior solution to the correspondence problem rather than to resist such a change.

The magnitude of the hysteresis effect is defined as the difference in the mean PTP on the ascending trials and the mean PTP on the descending trials. This difference was 17.58 and 12.00 arc minutes for the 48V and 32V displays, respectively. The size of the hysteresis effect, therefore, was not constant across the two display conditions. Thus, there is no absolute horizontal dot separation that must be exceeded before a VAM or a HAM percept can emerge.

In terms of the model of hysteresis shown in Figure 1, the PTP data provide an estimate of where each leg of the hysteresis loop crosses the X-axis. Clearly, the data are insufficient for the construction of a complete hysteresis loop. Such a loop can be approximated, however, if the responses to the 4-dot displays used to begin the ascending and descending sequences are also evaluated. A HAM percept was always reported on the first trial of every ascending sequence, in spite of the fact that the horizontal separation between dots of the initial display varied over a limited range. The horizontal dot separation never exceeded 16 arc minutes, however, on an initial trial. Therefore, it can be concluded that this value of horizontal separation always drove the percept to saturation; thus, a 16 arc minute dot separation can be used to locate the HAM saturation point (point D in Figure 1).

In like fashion, a VAM percept was always reported on the first trial of a descending sequence. The smallest horizontal dot separation

contained in any display shown on the initial trial of a descending sequence was 104 arc minutes in the 48V condition and 64 arc minutes in the 32V condition. Therefore, the VAM percept was taken to be at saturation when the horizontal separation was 104 arc minutes and 64 arc minutes for the 48V and 32V conditions, respectively.

Hysteresis loops for the 48V and 32V conditions were constructed from the PTP data and the responses to the initial trial of each type of trial sequence. These loops are shown in Figure 8, where spatial separation has been expressed as the logarithm of the ratio of vertical to horizontal dot distance. The hysteresis effect is evident in both the 48V and 32V conditions. Although there are slight differences in the curves across display conditions, the relative size of the hysteresis effect (i.e., separation between curves) was essentially the same for both conditions.

The results of this experiment provide support for the claim that prior correspondence, via the hysteresis effect, is a characteristic of the correspondence process. Other research on motion-detecting mechanisms in the human visual system has led to the belief that there may actually be at least two separate processes involved in the correspondence activity. It could be asked, then, if the hysteresis effect is differentially influenced by these different motion mechanisms. This question is addressed in the next experiment.

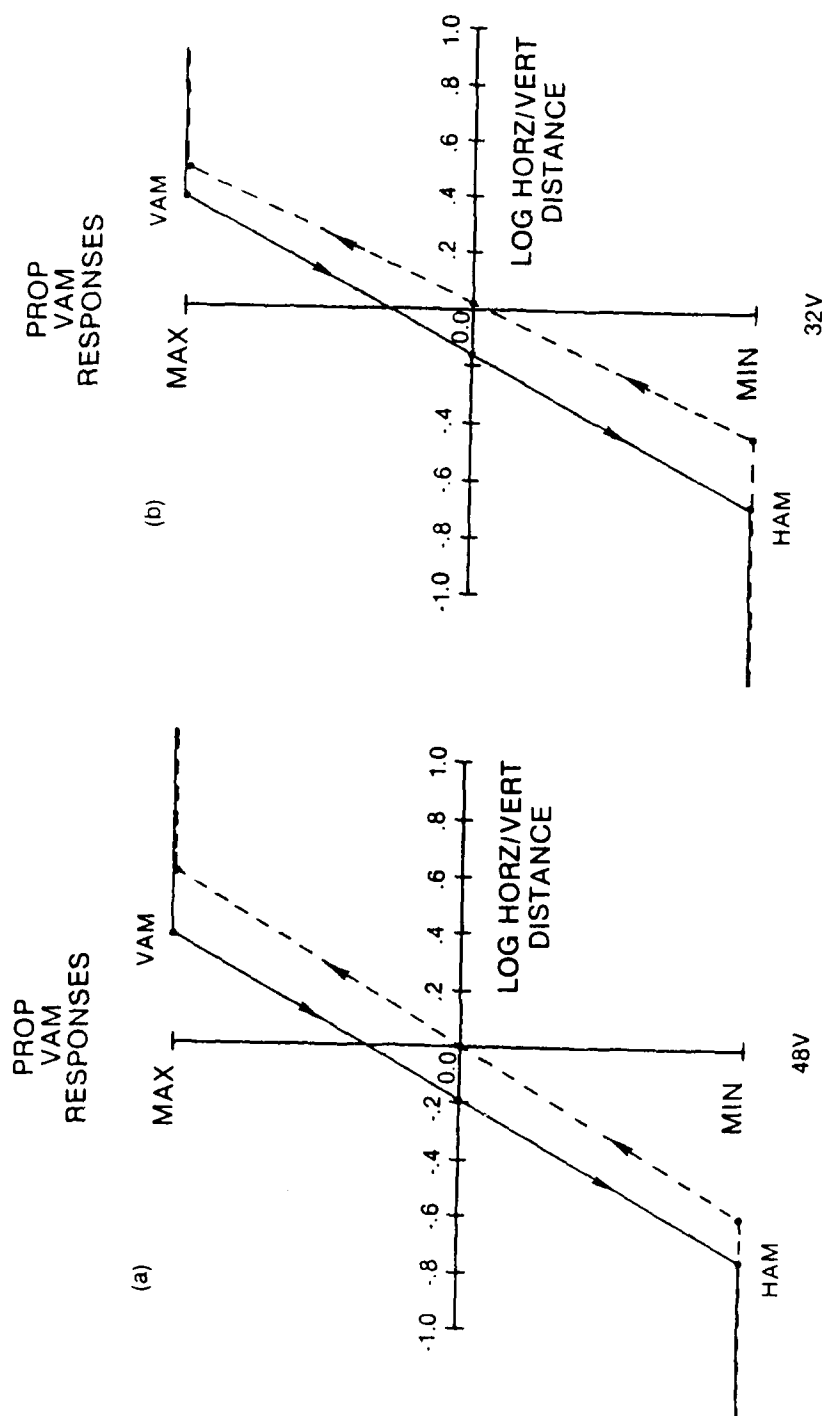


Figure 8. Relationship Between AM Percept and Horizontal Dot Distance Expressed as the Log Mean Horizontal/Vertical Dot Separation by 4-Dot Display Type (48V and 32V)

## EXPERIMENT II

### Background

As originally proposed by Wertheimer (1912), phi movement was believed to be a perception/sensation of raw movement itself, movement not attached to any object. Such "objectless" motion is rarely, if ever, experienced in the everyday world. We perceive "things" to move from one point in space to another. The perception of the movement of "things" constitutes one category of solution to the correspondence problem. The bat that rests just above the shoulder of the batter, for example, is the same bat as the one which moments later contacts the baseball out in front of the batter's body. The correspondence problem is solved by the formation of the perception of motion added to the perception of a "thing" (bat) rather than by the formation of the perception that there are two "things" (bats) at different points in space and in time. This category of solution to the correspondence problem, therefore, is probably contingent upon the activity of some kind of motion-detecting process in the human perceptual system.

Recent evidence supports a view that there are two, perhaps independent, motion processes (Braddick, 1973, 1974; Pantle and Picciano, 1976; Petersik and Pantle, 1979; Pantle and Petersik, 1980). Although several names have been used to identify the processes, they are most frequently called the long-range and short-range processes, terms originally introduced by Sir Oliver Braddick (1974). The long-range and short-range processes are distinguishable along several dimensions (see Anstis, 1981, for a review), perhaps the most notable is

in terms of their spatio-temporal range of operation. The short-range process, for example, is involved in the apparent motion of stimuli over only a very short spatial distance (less than about 20 arc minutes). Furthermore, the temporal separation between stimuli cannot exceed about 65 milliseconds. The long-range process, in contrast, can operate over this and a vastly larger spatio-temporal range--spatially on the order of degrees of visual angle, and temporally up to about 600 milliseconds.

Since the perception of motion (of a form/object) can enter into the solution to a correspondence problem, it is appropriate to ask whether or not the form of the solution is dependent upon which motion process contributes to the correspondence problem. If the correspondence process treats the outputs of the long-range and short-range process differently, then they would be expected to have different effects on the solution to a correspondence problem. The purpose of the current experiment is to ascertain how hysteresis, as an attribute of the correspondence process, is influenced when a correspondence problem has been constrained to meet the spatio-temporal limits of the short-range motion process.

In order to distinguish between the effects of the short-range and long-range mechanisms on the correspondence process, the term Case 1 is used to describe the situation where the test display is restricted to the spatio-temporal operating range of the short-range process. The term Case 2 is used to identify a test display whose spatio-temporal parameters exceed the upper boundary of the short-range process and, hence, fall in the domain of the long-range process.

The present experiment consists essentially of a replication of the last experiment but with the 4-dot display modified such that the vertical separation between dots was set at 16 arc minutes (16V). Based on the results of Experiment I, the ascending and descending mean PTPs with the new 4-dot display are expected to be 16 arc minutes or less. Therefore, the 16V display is likely to present a Case 1 correspondence problem. This is in distinction to the 48V and 32V displays, which presented Case 2 correspondence problems, since the spatial separation between dots in those displays exceeded the short-range process. If the short-range and long-range motion mechanisms make different contributions to the correspondence process, then the solution to the Case 1 (16V) and Case 2 (32V and 48V) correspondence problems should be different. Such a difference should be manifested in the magnitude of the hysteresis effect. If the magnitude of the hysteresis effect does not scale linearly across Case 1 and Case 2 correspondence problems, then it might be inferred that both the short-range and long-range motion mechanisms are involved in the correspondence process. A linear relation across Case 1 and Case 2 problems would suggest that only one motion mechanism is active in the correspondence process. Since only the long-range mechanism can operate over the spatial range of both Case 1 and Case 2 correspondence problems, this motion mechanism would be implicated.

#### Method

##### Subjects

Ten college students served as subjects as partial fulfillment of a course requirement to participate in a psychological experiment. All

subjects met the visual requirements indicated in Experiment I. They were inexperienced psychophysical observers and had no knowledge of the purpose of the experiment.

#### Apparatus

The apparatus and experimental arrangement were identical to that described in Experiment I, with three exceptions. The viewing distance was increased to 120 inches from 60 inches. The step change in horizontal separation between dots was reduced from 4 arc minutes to 2 arc minutes to maintain the same measurement accuracy over a smaller spatial range. Finally, two new display conditions were used--one (16V) with a vertical dot separation of 16 arc minutes and the other (32V) with a vertical dot separation of 32 arc minutes.

#### Procedure

The familiarization/training, practice, and M of L testing procedures employed in Experiment I were used without alteration. For descending M of L trials, the initial horizontal separation was randomly set from 72 to 64 arc minutes for the 32V display and 36 to 32 for the 16V display. For ascending M of L trials, the initial horizontal separations were randomly set from 4 to 8 arc minutes for both displays.

#### Results and Discussion

As in Experiment I, a percept transition point (PTP) was calculated for each ascending and descending series of trials and they were submitted to separate analyses for the 32V and the 16V display conditions. Individual mean PTPs, based on three measures each, are

presented in Table 3 for the two display conditions. The order of presentation of the two conditions was counterbalanced across subjects. Subjects 1 through 5 began with the 32V condition while Subjects 6 through 10 began with the 16V condition. A preliminary analysis of an order of presentation effect was performed on the mean subject PTP data. Separate t-tests were calculated for ascending and descending trials. All t-tests were found to be less than 1.0 and statistically nonsignificant. Accordingly, the PTP data from all subjects were pooled to form group mean PTP values. These values are presented as marginal means in Table 3 along with their standard deviations. All further analyses are based on the group means since the pattern of responses was the same for all subjects.

TABLE 3. MEAN HAM TO VAM (ASCENDING TRIALS) AND VAM TO HAM (DESCENDING TRIALS) PERCEPT TRANSITION POINTS BY SUBJECTS

32V			16V		
Subject	$\bar{X}$ ASC	$\bar{X}$ DSC	Subject	$\bar{X}$ ASC	$\bar{X}$ DSC
1	25	15	1	15	11
2	33	13	2	16	11
3	33	23	3	16	13
4	29	18	4	15	11
5	31	27	5	16	14
6	37	27	6	18	8
7	33	23	7	15	13
8	27	23	8	13	9
9	31	24	9	15	7
10	25	19	10	15	21
$\bar{X}$	30.4	21.2		15.4	10.9
SD	3.89	4.78		1.26	2.13

A hysteresis effect was again found for both display conditions. The mean vertical-to-horizontal perceptual transition point (V-H PTP) was 21.2 and 10.9 for the 32V and 16V displays, respectively. The mean horizontal-to-vertical (H-V) PTPs were 30.4 and 15.4 for the 32V and 16V displays, respectively. That the difference in PTP transition across display type was statistically significant was confirmed by a repeated measures ANOVA [ $F(1,9) = 120.82, p < .001$ ].

TABLE 4. MEAN ASCENDING AND DESCENDING PTPs (ARC MINUTES)  
FOR THE 32V DISPLAY BY EXPERIMENT

	32V	
	$\bar{X}$ ASC	$\bar{X}$ DSC
Experiment I	33.5 (5.66)	21.5 (2.71)
Experiment II	30.4 (3.89)	21.2 (4.78)

Because a 32V display condition was used here and in Experiment I, there is an opportunity to empirically check the consistency of results across experiments. The mean PTP values and associated standard deviations from both experiments for the 32V display are shown in Table 4. It is clear by inspection of the PTP values that there was little difference in PTP response across experiments. The slight difference in the mean ascending PTP values (33.5 versus 30.4) is probably due to a change in measurement sensitivity. The step change in horizontal separation used in Experiment I was 4 arc minutes, as opposed to the 2 arc minutes step change used in the present experiment. Thus, a 2 arc minute difference in mean PTP between the experiments is expected solely on the basis of the difference in measurement sensitivity.

The primary purpose of the present experiment was to evaluate the relationship between a prior correspondence effect (i.e., hysteresis) and the long-range and short-range motion mechanisms. It was hypothesized that the magnitude of hysteresis would not scale linearly across Case 1 (short range) and Case 2 (long range) correspondence problems. One way to test the linearity hypothesis is to express the magnitude of hysteresis as a proportion of vertical dot separation. Given linear scaling, the proportionalized data would yield a constant value for all of the vertical dot separation (4-dot display) tests in this and the last experiment.

The differences between the mean descending and the mean ascending PTP values were calculated by subject for the 16V and 32V displays, and expressed as a proportion of the vertical dot distance. These values are shown in Figure 9 for the 16V and 32V display conditions. Comparable data for the display conditions of the last experiment are also shown in the figure. It should be noted that the data across conditions within a single experiment (either Experiment I or II) were from the same subjects, while the data across experiments were for different sets of subjects.

The proportionalized data from the present experiment were essentially the same for the 16V and 32V conditions--.28125 and .28750, respectively. These values changed to .3750 and .36625 for the 32V and 48V conditions, respectively, of Experiment I. The relationship between the two data sets is shown clearly in Figure 9.

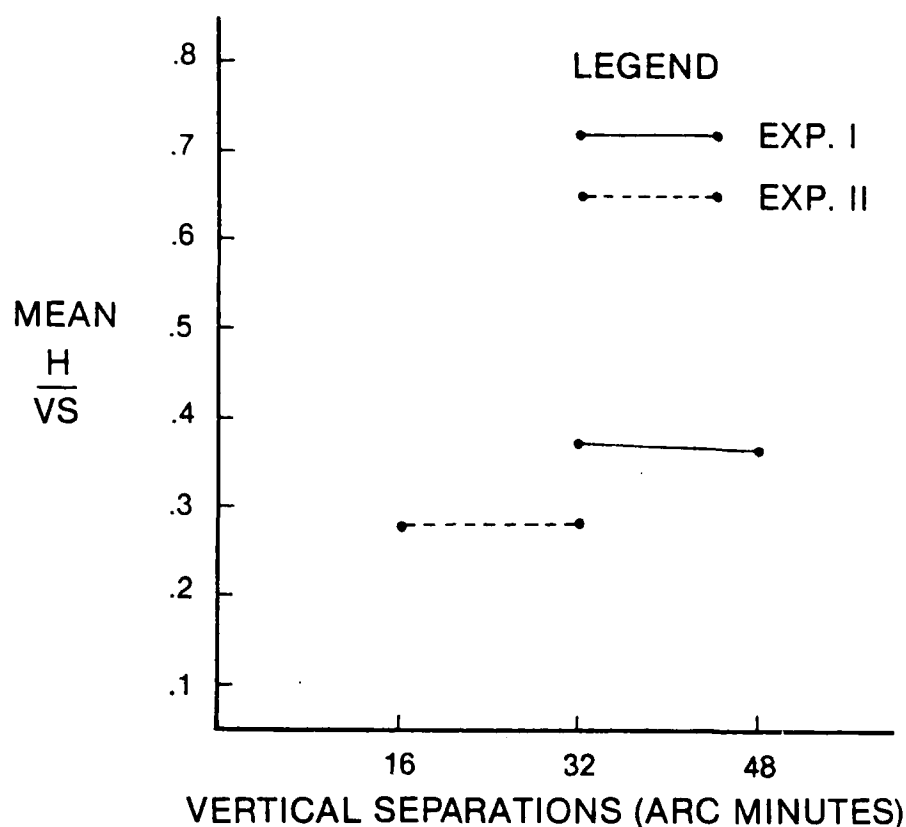


Figure 9. Mean Ratio of the Magnitude of Hysteresis (H) to Vertical Dot Separation (VS) for Three Vertical Separations

It seems clear from Figure 9 that the magnitude of hysteresis scaled approximately linearly over the two vertical dot separations used in each individual experiment, but that the constant of proportionality was different between the two experiments. The difference in the proportionality constant across experiments may have been due to (1) a difference in measurement sensitivity between experiments (discussed earlier), (2) subject differences across experiments, or (3) both of these factors.

A series of three t-tests was performed to assess the relationship between test conditions, both within and across experiments. The related t-test comparing the 16V and 32V conditions of the present experiment was not significant ( $t = -0.1851$ ,  $p > .05$ ), nor was the related t-test comparing the 32V and 48V conditions of the last experiment ( $t = 0.1107$ ,  $p > .05$ ). A nonrelated t-test was performed to evaluate the difference between scores to the 32V condition of each experiment. This test also produced a nonsignificant result ( $t = 0.9749$ ,  $p > .05$ ).

Taken together, these analyses imply a single constant of proportionality can be used to describe the magnitude of hysteresis for 4-dot correspondence problems whose vertical spatial separation are in the range of 16 to 48 arc minutes. In other words, the magnitude of hysteresis is a linear function of vertical dot separation, at least over the spatial range tested. Additionally, because the magnitude of the hysteresis effect was found to be linear over a set of Case 1 and Case 2 problems, there is no evidence that the correspondence process is affected differently by the two motion mechanisms. Moreover, because all three display conditions satisfied the spatio-temporal parameters of only the long-range mechanism, this mechanism alone could have mediated the AM percepts induced by the 4-dot correspondence problems. Thus, it is most parsimonious to conclude that only one motion mechanism is a factor in the prior correspondence effect under investigation.

### EXPERIMENT III

#### Background

In the preceding two experiments, evidence for visual hysteresis was manifest empirically as a change in the locus of the PTP during ascending and descending series of the M of L. The M of L paradigm was chosen initially since this procedure allowed the independent variable (horizontal separation) to be manipulated in a manner expected to optimize the hysteresis effect. Historically, the M of L paradigm has been criticized on the grounds that it is highly susceptible to the so-called response bias errors of anticipation and habituation (see Kling and Riggs, 1972). Unfortunately, the error of habituation, like hysteresis, also predicts PTP values that are different for ascending and descending trial sequences. Moreover, the differences in PTP values that result from the error of habituation are in the same direction as the differences predicted by visual hysteresis. Consequently, from a historical perspective, the hysteresis effect would be treated as a simple example of the error of habituation.

An interpretation of the PTP data as a type of response bias error offers a serious challenge to the notion of hysteresis. This challenge stems from a paradigmatic weakness of the M of L procedure. Because the independent variable is changed in a stepwise manner, the subject may, perhaps out of boredom or simply inattention, persevere a response well beyond the point where the actual sensory/perceptual experience has changed. Unfortunately, it is just this method of stimulus presentation that makes the M of L technique attractive for the investigation of

hysteresis. The knowledge of hysteresis gained from physical systems (e.g., magnetic induction) indicates that a gradual, stepwise change in force is best for manifesting hysteresis; if this feature of the M of L technique is eliminated, one may also eliminate the ability to detect hysteresis itself.

Confidence in the validity of the hysteresis concept would obviously be increased if it could be demonstrated to exist in a manner that would either eliminate or substantially reduce the merits of a response bias interpretation. To achieve this objective, a new paradigm for the collection of psychophysical data was developed. This psychophysical procedure has been called the Method of Interleaving Anchors (MIA). The purpose of the present experiment is to demonstrate hysteresis within the context of the new paradigm. Since the MIA procedure has not been used heretofore, I shall describe the procedure before presenting the experimental methodology.

#### Method of Interleaving Anchors (MIA)

The Method of Interleaving Anchors includes the presentation of two or more anchor displays and a set of test displays. The displays are presented in a quasi-random order, with the test displays presented according to a random schedule between a structured presentation of the anchor displays.

A diagram of the MIA paradigm is presented in Figure 10. As shown, this illustration includes two anchor displays, A and B, and two test sets, a and b. The anchor and test displays differ in that each anchor display gives rise to a single solution to a given correspondence

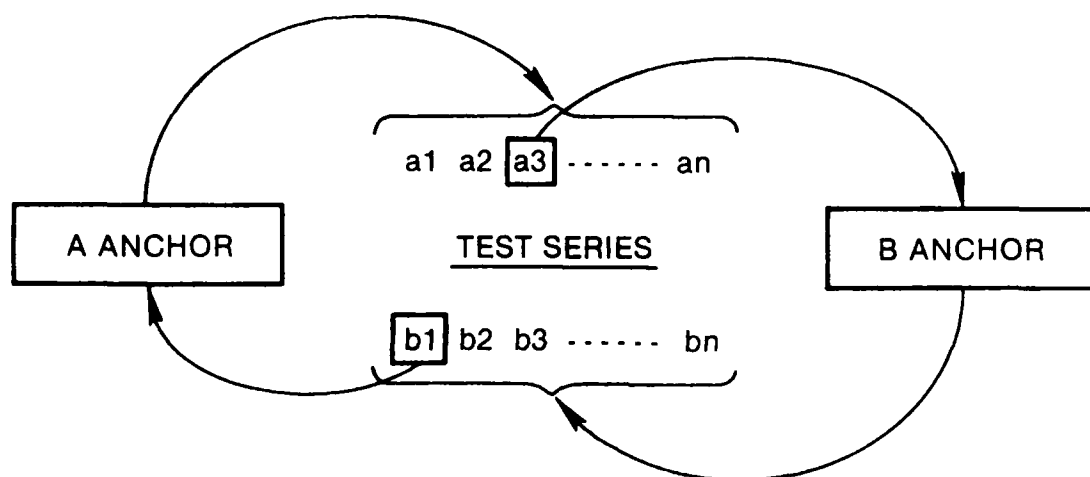


Figure 10. An Illustration of the Method of Interleaving Anchors (MIA)

problem, while each test display yields more than one solution to the same problem. That is, each anchor display induces a different stable percept (i.e., a state of percept saturation). The test displays, however, are ambiguous in that each can induce two or more percepts. In terms of the 4-dot display, the A and B anchors would be the display configurations used to initiate the ascending and descending series in the previous experiments. Test displays would be composed of horizontal separations between those used to define the A and B anchors.

The MIA procedure begins with the random selection of either the A or B anchor. The selected anchor display, say A, is presented and then followed, in turn, with a presentation of (1) one test display chosen at random from set "a," (2) the B anchor, and (3) one test display chosen at random from set "b." As indicated in Figure 10, for example, an MIA cycle begins with the presentation of the A anchor. Next, the  $a_3$  test display (randomly selected) is presented. This is followed by the B

anchor. Finally, the b1 test display (randomly selected) is presented. This sequence of four presentations completes one cycle through the MIA procedure. The complete paradigm consists of a set of these presentation cycles, with the number of cycles determined by the investigator.

It should be clear that with the MIA paradigm a display from the "a" test sets (randomly selected) always follows a presentation of the A anchor. Similarly, a display from the "b" test sets (randomly selected) always follows a presentation of the B anchor. If the "a" and "b" test sets are composed of the same members (i.e.,  $a_1=b_1$ ,  $a_2=b_2$ , ...,  $a_n=b_n$ ), then the identical test displays would be presented immediately after each anchor display. Consequently, the influence of a known prior correspondence problem (i.e., that offered by the anchor displays) on each of the test displays can be determined. If, for example, the proportion of VAM percept responses induced by the "a" series of test displays were greater than the proportion of VAM percept responses to an identical "b" series, then there would be reason to believe that these responses were influenced by the anchor displays; otherwise the percepts induced by the "a" and "b" series should be the same, since the displays were perfectly matched across the two test series. Clearly, if more VAM percepts were elicited by test displays shown immediately after a vertical AM anchor than by test displays presented immediately after a horizontal AM anchor, this would constitute evidence for hysteresis.

In the present experiment, five versions of the 4-dot display comprised each test series. These displays differed only in terms of the horizontal separation between dots. The horizontal separations were restricted to the range of values defined by the high and low PTPs found in Experiment I. Thus, in terms of classical threshold research, the test display configurations spanned the zone of uncertainty (Egan, 1972). The horizontal separations for the VAM and HAM anchor displays were set at points about  $\pm$  two standard deviations away from the mean PTP found in Experiment I for the 48V display.

In accordance with the hysteresis hypothesis, it was predicted that the proportion of VAM percepts would be greater on the test series that immediately followed the presentation of the VAM anchor display than on the test series that immediately followed the HAM anchor display. Since the displays in each test series varied in terms of horizontal dot separation, the proportion of VAM responses was also expected to increase monotonically with horizontal dot separation for both test series.

### Method

#### Subjects

Ten undergraduate students meeting the visual requirements outlined in Experiment I served as subjects. All of them were inexperienced psychophysical observers, and they had no knowledge of the purpose of the experiment.

## Apparatus

The apparatus and experimental arrangement were identical to that used in Experiment I, including the design of the Training Display (TD), 4-dot experimental display (ED), and the fixation target.

## Procedure

Each subject participated in one experimental session, which lasted approximately 60 minutes. It was divided into three parts: familiarization, practice, and testing. The procedures followed in each of these phases are described below.

Familiarization Phase. The procedures used in this phase were identical to those used in Experiments I and II. Basically, the subject was exposed to a modified 4-dot display designed to insure that each subject would experience both the vertical and horizontal AM percepts. As stated earlier, the primary purposes of this portion of the experiment were (1) to familiarize each subject with the general types of motion they would experience in the experiment proper; (2) to avoid an instructional set with respect to how to perceptually organize the display information, since both versions of the TD display were ambiguous and could both stimulate either a vertical or horizontal AM percept; and (3) to allow time for the subjects to completely adapt to the ambient illumination conditions.

Practice Phase. The purpose of this phase was to familiarize the subject with (1) the self-paced, automatic stimulus generation equipment, (2) the response recording equipment, and (3) the range of stimuli to be

used in the experiment. After receiving an explanation of how to operate the joystick/fire control apparatus, each subject was given time to practice using the equipment. During practice, the 4-dot display was used. It was modified on each trial by a fixed incremental increase or decrease in the horizontal separation between display elements (i.e., an M of L technique was used). The subjects continued practice until they felt comfortable with the procedures for both initiating a trial and making the appropriate response with the joystick to indicate either vertical or horizontal AM. Once this procedure could be followed reliably, the practice session was terminated. Generally, this took anywhere from 12 to 20 display presentations.

Experimental Phase. The procedures used in this phase were essentially the same as those employed in the experimental portion of Experiment I. The primary difference was that seven different 4-dot displays were used, and they were presented in accordance with the MIA paradigm. Two of these seven display configurations served as anchors for the opposing AM percepts elicited by the 4-dot display. The remaining five displays constituted the test set. In all of the displays, vertical element separation was 48 minutes of visual angle. The horizontal separation between display elements for the two anchor displays (VAM and HAM) was 60 minutes and 12 minutes, respectively. The five horizontal separations for the test displays were 28, 32, 36, 40, and 44 minutes. These displays will be called T1 through T5, respectively. The presentation sequence followed the MIA paradigm and always began with the VAM anchor display, after which one of the five test displays was selected at random for presentation. Next, the HAM anchor display was presented, and then

another randomly selected test display was shown. This completed one cycle of the MIA technique. Fifteen MIA cycles were completed in the first block of the experiment. Independent randomization routines were used to select test displays for presentation after each of the percept anchors. Randomization was constrained so as to allow an equal number of presentations of each test display. Therefore, after one block of presentations, each anchor display was presented 15 times. Each test display was presented three times after the VAM anchor and three times after the HAM anchor. Thus, each subject made 60 responses in total, one after each display (anchor and test) presentation, to indicate whether a VAM or HAM percept was experienced. A 2-minute break was provided before a second block of 15 MIA cycles was presented. Thus, a complete experimental sessions consisted of 30 presentations of each anchor display and 12 presentations of each test display, six after each anchor display. All displays were presented in a self-paced fashion under the control of the subject. Responses were registered by movement of the joystick in the appropriate direction--vertically for a VAM response and horizontally for a HAM response.

### Results and Discussion<sup>3</sup>

For the purpose of analysis, the AM percepts reported on each test trial by a subject were partitioned into two separate data sets--one

<sup>3</sup>To facilitate discussion, the terms VAM and HAM will be reserved for the description of the percept that emerges after viewing a test display. Vertical or horizontal AM occurring at any other time, such as with an anchor display, will not be identified as a VAM or HAM percept. It will be described as either vertical/horizontal motion or vertical/horizontal AM. This distinction will be maintained through the remainder of the paper.

consisting of responses made to test 4-dot displays that followed a presentation of the HAM anchor display, and the other containing responses made to test displays that followed a presentation of the VAM anchor display. These data sets will be referred to as the HAM anchor data and the VAM anchor data, respectively. The proportion of VAM responses induced by each test display was calculated separately for the two data sets. Since the pattern of responses was the same for all 10 subjects, only mean data are reported. The mean proportion of VAM responses (based on six observations per subject) is plotted in Figure 11 as a function of the horizontal separation (HSEP) of dots contained in the test displays. Also shown is the proportion of vertical AM reports made to the anchor displays. These latter data points are based on 30 responses per subject.

It is readily apparent from the figure that the proportion of VAM percepts induced by displays in the VAM anchor test series was in every instance higher than the proportion of VAM responses to the same display configurations obtained in the HAM anchor test series. In addition, the number of VAM percepts increased monotonically as HSEP was increased across displays. This was true for both test series. Both of these results are consistent with the hysteresis hypothesis.

The data were submitted to a 5 by 2 ANOVA with repeated measures on both factors to test the significance of the hysteresis effect. The two factors were: (1) horizontal separation (HSEP) of the 4-dot display (five levels), and (2) test series, as defined by the type of preceding anchor display (two levels). These factors will be identified as HSEP and Anchor, respectively. The ANOVA revealed a significant main effect

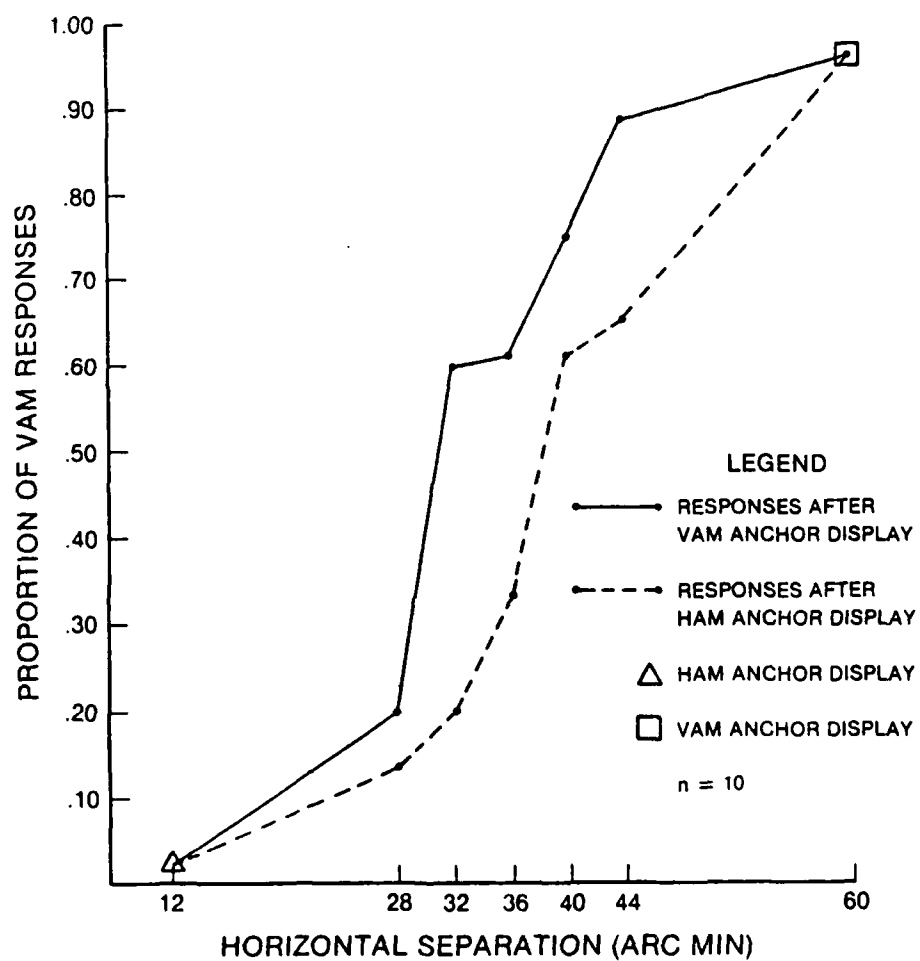


Figure 11. Proportion of Vertical AM Percept (VAM) Responses as a Function of Horizontal Separation Between Elements of the 4-dot Display

for both the HSEP and Anchor factors [ $F(4,36) = 34.64$  and  $F(1,9) = 111.91$ ,  $p < .001$ , respectively]. The HSEP by Anchor interaction was not significant [ $F(4,36) = 2.44$ ,  $p < .10$ ].

The significant main effect of the Anchor factor indicates that the mean difference between the two curves in Figure 11 is reliable and adds statistical support to the claim that the correspondence process is affected by hysteresis. The spatial range of dot separations over which hysteresis operates, however, does seem to be limited. The location of these limits was approximately defined by the horizontal dot separations incorporated in the VAM and HAM anchor displays (see Figure 11). The proportion of vertical AM responses to the VAM and HAM anchors was 0.96 and 0.027, respectively. This indicates that the solution to the correspondence problem provided by the anchor displays was almost unequivocal in each case; thus, at these dot separations, percepts induced by the test displays apparently had no explicit effect on the anchor displays. That is, prior correspondence, in terms of hysteresis, appeared to be nearly ineffective when the horizontal distance between dots in the 4-dot display exceeded 60 arc minutes or was less than 12 arc minutes, as in the anchor displays.

Furthermore, the magnitude or "strength" of hysteresis as indicated by the distance between the two curves in Figure 11 is not constant over the five vertical dot distances used to define the test displays. Like the previous experiments, this indicates that the hysteresis effect is influenced by a spatial distance parameter of the 4-dot display.

The results of this experiment provide more evidence in support of visual hysteresis. Moreover, it eliminates, or at least strongly reduces, an interpretation of the data in terms of a response bias error. The primary virtue of the MIA paradigm is that it allows control over the error of habituation while at the same time it preserves the potential for a prior correspondence solution to manifest itself in the response data. This is a difficult task since response perseveration in the observable pattern of data is used to objectively define both the concept of hysteresis and the concept of habituation. The two terms differ, however, in at least three important respects. First, the hysteresis effect is most likely a perceptual-level phenomenon, while habituation is most likely a judgment-level or higher-order cognitive phenomenon. Second, hysteresis is theoretically operative all of the time, whereas habituation is dependent on a linear presentation order of stimuli. Third, the concept of hysteresis is tied to a theory of perception (correspondence theory) while the notion of habituation was originally advanced to simply account for an otherwise unexplainable systematic discrepancy in nearly all threshold data collected with the M of L psychophysical procedure.

The author and several of his colleagues have viewed the dynamic 4-dot display with the intent of achieving a particular percept, say VAM. Even given this bias in favor of a particular solution to the correspondence problem offered by the 4-dot display, the experienced percepts changed between VAM and HAM in the same manner as when a bias was not invoked. Therefore, it may be tentatively concluded that the hysteresis effect cannot be brought under conscious control; hence, it

is most likely a phenomenon that does not involve much in the way of control processing (Shiffrin and Schneider, 1977). It has been customary to view factors involved in the processing of sensory information as occurring on a perceptual level when little apparent cognitive activity is involved in the process. Thus, the hysteresis effect is viewed here as a perceptual process.

The habituation effect is not as immune from conscious bias as the hysteresis effect seems to be. Although habituation need not always be under conscious control, one certainly often becomes aware they are habituating when it occurs; and this awareness, by itself, may influence the pattern of habituation in real time. That is, one may consciously decide to change his/her response because one perceives himself/herself to have been habituating. Such a consciously directed alteration of a series of responses can eliminate habituation if it is a cognitive decision, while the same conscious direction would not alter a perception, if it were under peripheral behavioral control. Since habituation is considered to be a response bias and, hence, by definition, potentially under cognitive control, and hysteresis does not seem to be controllable by the subject, the variable of conscious control can be used to distinguish between the two concepts. It is on this basis that I have classified the hysteresis effect as a perceptual (no conscious control) phenomenon and habituation as a cognitive (potential cognitive control) phenomenon.

In order for habituation to occur, a person must make a series of responses to a stimulus whose changes of magnitude are small enough to go unnoticed. Since the M of L paradigm orders the presentation of

stimuli in a linear, stepwise manner with respect to a change in magnitude, it provides a situation where response biases are likely to occur. Two response biases have been identified with this psychophysical technique. These are the so-called errors of habituation and anticipation. The anticipation error is the opposite of the habituation error. Anticipation describes the situation where a person makes a categorical change in response before it is warranted on the grounds of stimulus magnitude. It is important to note that in Experiments I and II, where the M of L paradigm was used, not one subject showed any sign of an anticipation response bias. All of the data were consistent with the hysteresis hypothesis and, therefore, also consistent with the notion of habituation. Since there were no anticipators in these experiments, which would not be expected on the basis of sampling theory, it is difficult to defend a response bias interpretation of the data. On this basis alone, it is reasonable to conclude that the observed lag in effect behind cause was perceptual in nature and a manifestation of hysteresis.

Evidence for hysteresis was also found in the present experiment when a new psychophysical paradigm was used. If it is assumed that a series of at least two identical responses is needed before one could even begin to habituate, then the MIA paradigm offers little opportunity for this response bias to occur. Trials with linearly increasing or decreasing stimulus magnitudes are not presented. The two anchor displays surround the presentation of each randomly selected test display. Since the responses to these anchors are almost always opposite to each other, the same response (percept) will not occur more than

three times in succession before an opposing response intervenes. This does not give habituation much time to develop. Furthermore, habituation would have to be reinstated after every four trials (two test and two anchor displays) for the effect to be sustained over several cycles of the MIA paradigm. Thus, the interleaving of anchor displays with test displays provides a test procedure that should be quite resistant to both errors of habituation and errors of anticipation. Such resistance is advanced further by a randomization of the order of presentation of the test displays.

An informal debriefing of the subjects in this experiment revealed that each of them perceived all of the stimuli to be presented in a random order. Consequently, there was no cognitively recognized stepwise pattern of trials to encourage the activation of habituation. This finding, along with the fact that the MIA paradigm has a structure that counters the development of habituation, leads to the conclusion that the observed lag in effect behind cause is best conceived to be a perceptual level phenomenon.

A final argument in support of the hysteresis concept rests on theoretical considerations. The notion of a response bias was originally advanced to account for systematic fluctuations in threshold data that were neither predicted nor explained by the prevailing theories of sensory thresholds. The concept itself was not formed, therefore, on the basis of a theory of sensation or perception. The concept of hysteresis, on the other hand, has not been advanced to reconcile data with theory; rather it is seen as an integral part of the process of perception from the perspective of correspondence theory. Correspondence

theory is still in its infancy, and hysteresis has not been explicitly derived from any particular tenets of this theory. Nevertheless, since the hysteresis concept has not been invoked to merely "explain" data, it probably has greater potential than a response bias concept to provide insight into the underlying processes of perception. For this reason, as well as the others presented earlier, it seems useful to view the results of Experiments I through III as evidence for visual hysteresis as an aspect of the correspondence process.

#### Experiment I and III Results Compared

It is difficult to make direct comparisons between the results of this experiment and Experiment I due to differences in the form of the data. Data from the MIA paradigm can be used to establish several different estimates of the strength of a percept (e.g., either VAM or HAM). This is possible since multiple responses to several preset display configurations are recorded and proportional data can be derived therefrom. The M of L technique is limited in that data are provided only for one level of percept strength, that being at the PTP. Henrick (1967) has proposed, however, that the data contained in an M of L experiment can be transformed into proportional form. Such a transform of the M of L data would allow estimates of percept strength to be made at several different horizontal dot separations. This transformed data could then be used to define a hysteresis loop in greater detail.

As indicated in Experiment I, with the M of L technique, incremental changes are made in a stimulus pattern until a PTP is reached. Two PTP values are derived, one based on an ascending series

and the other on a descending series. Several estimates of the PTP value are usually found in the course of an experiment for both the ascending and descending series. If one calculates the number of times (observers) a particular horizontal separation value was selected as the PTP, then this number can be used to establish the proportion of times the PTP was located at each possible horizontal dot separation. Separate estimates of the location of the PTP, in terms of horizontal separation, can be gained independently for ascending and descending serial orders. By calculating the cumulative proportion of PTP responses across trials for each of these series, the probability of the PTP falling at, below, or above a particular horizontal separation value can be determined. In this manner, data from the M of L paradigm can be made comparable, at least to a first approximation, with data from the MIA paradigm. This is essentially the technique used by Henrick to equate data across the M of L and Method of Constant Stimuli psychophysical procedures.

The above procedure was used to transform the PTP data for the 48V display configuration from Experiment I into proportional data. The results of this transformation are portrayed in Figure 12. Since an HSEP value of 14 always resulted in a HAM percept, regardless of whether an ascending series or a descending series of trials was used, this value can be treated like a HAM anchor. In a similar manner, an HSEP of 66 can be treated like a VAM anchor display. The ascending and descending cumulative probability curves, then, can be viewed as a hysteresis loop similar in nature to the one derived with the MIA paradigm (see Figure 12). A comparison of the hysteresis loops across

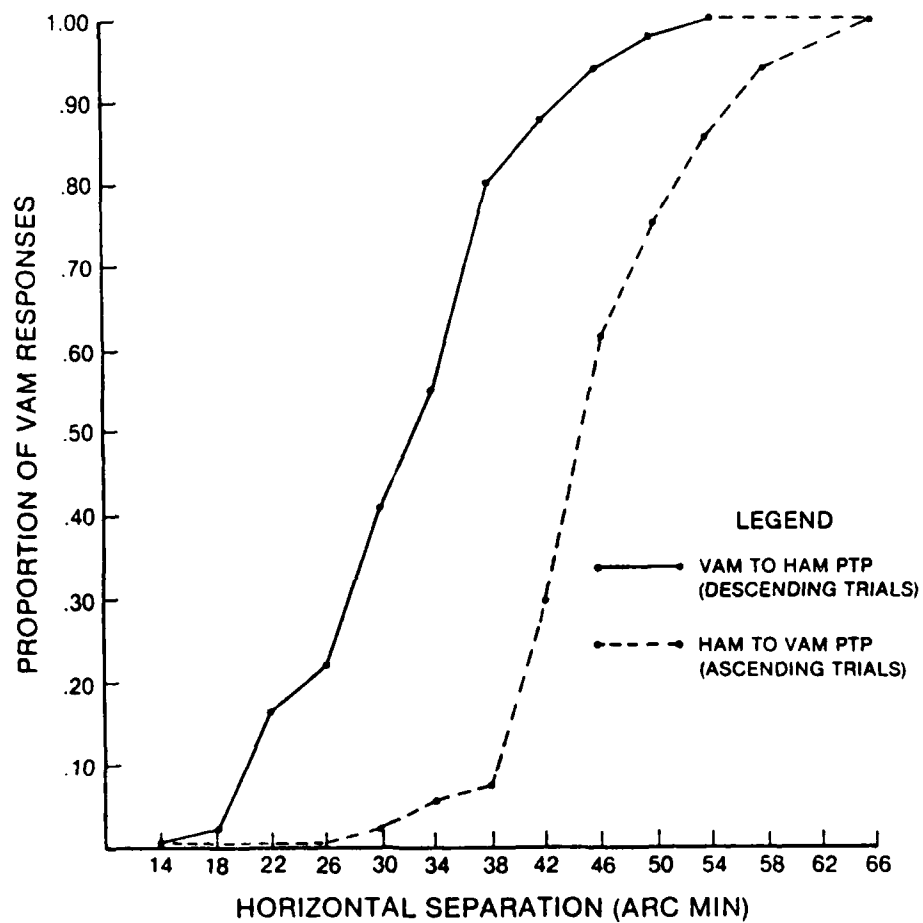


Figure 12. PTP Data from Experiment I Expressed in Terms of the Proportion (Cumulative) of Observations That Yielded a VAM Percept (See text for a discussion of the data transformation procedure.)

Experiments I and III makes it clear that the lateral separation between the two legs of the loop is larger for the M of L data set (see Figures 11 and 12). The magnitude of hysteresis at the 0.50 VAM percept point, for example, is estimated at about 12 arc minutes from the M of L data and at only about 8 arc minutes from the MIA data. This difference may be due to several factors. First, a habituation error may have summed with the hysteresis effect in the M of L data. Second, it may have been caused by the differences in the way the data were handled across the psychophysical techniques [i.e., a comparison between cumulative probabilities (M of L data) versus noncumulative probability data (MIA data)]. Third, it may be a reflection of a differential sensitivity of the psychophysical techniques to capture the hysteresis phenomenon. This last possibility stems from the fact that with the M of L procedure, several exposures to displays which yield the same percept always preceded the display leading to a change in percept. The magnitude or strength of the prior correspondence offered by this total series of displays may well have exceeded the magnitude of prior correspondence offered by a single anchor display or by a variable series of displays in the MIA procedure. If the MIA procedure were modified such that one anchor display was presented several times prior to a test display, then the size of the hysteresis effect might be increased. This hypothesis was tested in the next experiment.

## EXPERIMENT IV

### Method

#### Subjects

Six undergraduate college students participated in the experiment in order to partially satisfy a course requirement. All subjects possessed normal vision according to their own reports. All subjects had received an eye examination by a qualified health care professional during the past two years. Each of them served in one 60-minute (approximate) session. All were inexperienced psychophysical observers who were naive with respect to the purpose of the experiment.

#### Apparatus and Visual Displays

The display generation and response recording equipment was the same as that used in the previous experiments. As before, the display was viewed from a distance of 60 inches under low ambient illumination conditions. The training, familiarization, test, and anchor displays used in Experiment III served as stimulus material.

#### Procedure

The basic three-phase procedure of familiarization, practice, and testing used in Experiment III was followed. The practice session was modified, however, to include a sequential series of five presentations of the vertical anchor displays prior to each test display. After each anchor display, the subject reported verbally what AM percept was experienced. Responses to the test displays were recorded in the usual

manner (i.e., joystick response). Display presentation was self-paced. After 60 test display presentations, subjects were given a 2-minute break, and then an additional 60 test trials were presented.

The spatio-temporal parameters of the displays were identical to those used in Experiment III. The major departure from the procedure of the previous experiment was the inclusion of repeat presentations of the VAM anchor displays. All experimental sessions began with the VAM anchor display. Five VAM displays were presented in series. These displays were separated by a blank (black) frame which lasted approximately 500 msec. At the conclusion of the fifth presentation, the fixation target was reimaged on the monitor and the remainder of the sequence followed that used in the last experiment. Thus, one cycle through the display sequence included (in order) five VAM anchor displays--test display--one HAM anchor display--test display. Verbal responses were made after each presentation of the VAM anchor displays, or after the total series of five presentations was completed, at the option of the subject.

### Results and Discussion

As before, the AM percepts reported on each test trial were partitioned into VAM anchor and HAM anchor data sets. The proportion of VAM percepts was then calculated separately for the two data sets. Since the pattern of responses was the same for all subjects, only mean data are reported. Group means, based on 36 reports each, are plotted in Figure 12 for the five test displays. Also shown is the proportion of VAM responses to the two anchor displays. The data point for the VAM

anchor is based on 900 responses, while the data point for the HAM anchor is based on 180 responses.

As can be seen from Figure 13, a higher proportion of VAM responses was made to test displays presented immediately after the VAM anchor displays than to the same test displays presented immediately after the HAM anchor displays. Thus, the data show evidence of a hysteresis effect. The mean separation between the VAM and HAM data sets is statistically significant [ $F(1,5) = 33.75$ ,  $p < .001$ ].

As in the last experiment, the distance between the two legs of the hysteresis loop can be used to estimate the magnitude of the hysteresis effect. The two functions in Figure 13 are separated by about 8 arc minutes at the 0.50 VAM response level. This is essentially the same value found in Experiment III (see Figure 11). Thus, with respect to this index, five consecutive repetitions of the VAM anchor display did not alter the size of the hysteresis effect from that found when only a single presentation of an anchor display was made prior to a test display.

Since only one of the two anchor displays used in this experiment was repeated, there was an asymmetry in the trials that constituted each cycle of the MIA paradigm. It is possible that this asymmetry may have caused a differential effect of prior correspondence on the two functions that comprise the hysteresis loop. It might be expected, for example, that the descending leg of the loop (VAM to HAM change) would be elevated (i.e., show an increase in proportion of VAM responses) because of the five repeat VAM anchors, while the ascending leg (HAM to

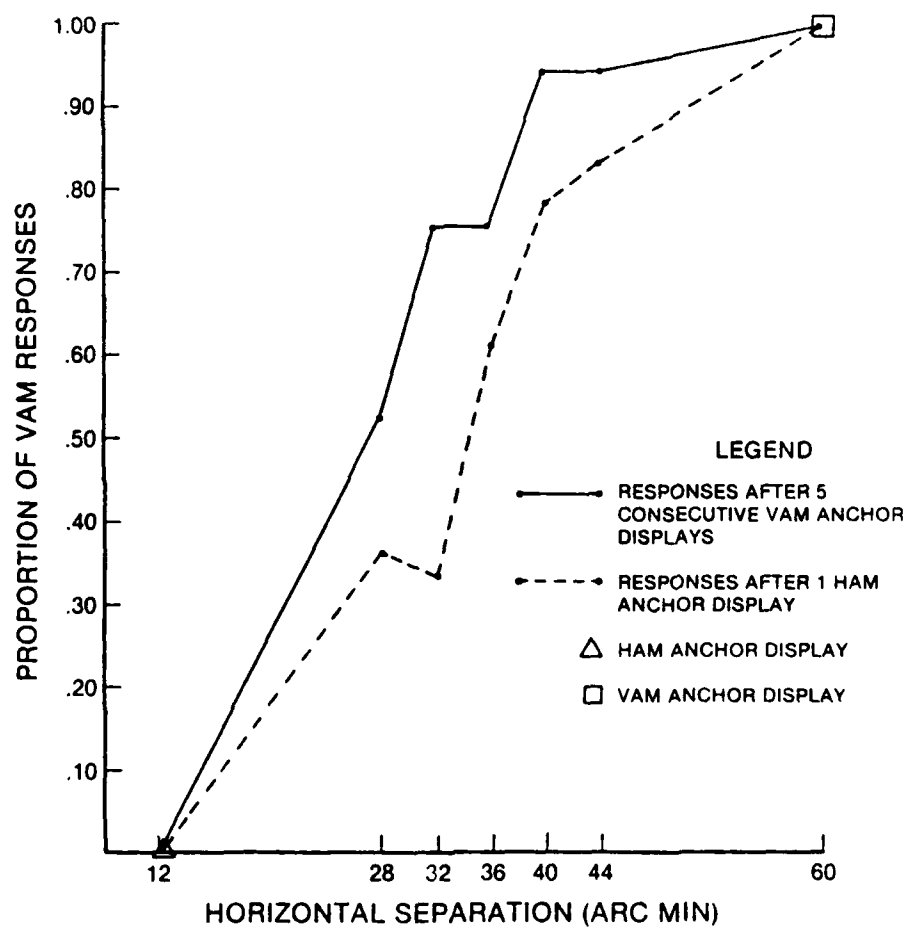


Figure 13. Proportion of Vertical AM (VAM) Percept Responses as a Function of the Horizontal Separation Between Elements of the 4-dot Configuration

VAM change) would not be changed from Experiment III since it did not benefit from multiple presentations of a prior HAM anchor. It is also possible, however, that the repeat VAM anchor series would increase the strength of a VAM percept so dramatically that its effect might extend even to the test displays presented after a HAM anchor. If so, VAM and HAM curves would both be expected to be shifted upward, but the difference between them might remain relatively unchanged.

VAM response data from both Experiments III and IV are shown in Figure 14. For ease of comparison, each leg of the hysteresis loop is shown in a separate panel. Panel "a" shows the proportion of VAM responses to the test displays presented immediately after the VAM anchor display. This is the VAM data set. Panel "b" displays the same type of response data to the same test display made after a single exposure to the HAM anchor display. This is the HAM data set.

It is clear from Figure 14 that the repeat VAM anchor series of Experiment IV caused an overall increase in the proportion of VAM percepts reported by the subjects. This increase is evident in both the VAM and HAM data sets (see Figure 14a and 14b). The magnitude of the increase appears to be slightly larger with the HAM data, but this may be due in large part to a ceiling effect in the VAM anchor condition at large horizontal dot separations.

To assess the reliability of the findings, the VAM response data from both Experiments III and IV were submitted to an ANOVA. Because of differences in sample sizes across the two experiments, an unweighted means analysis procedure (Keppel, 1973) was used.

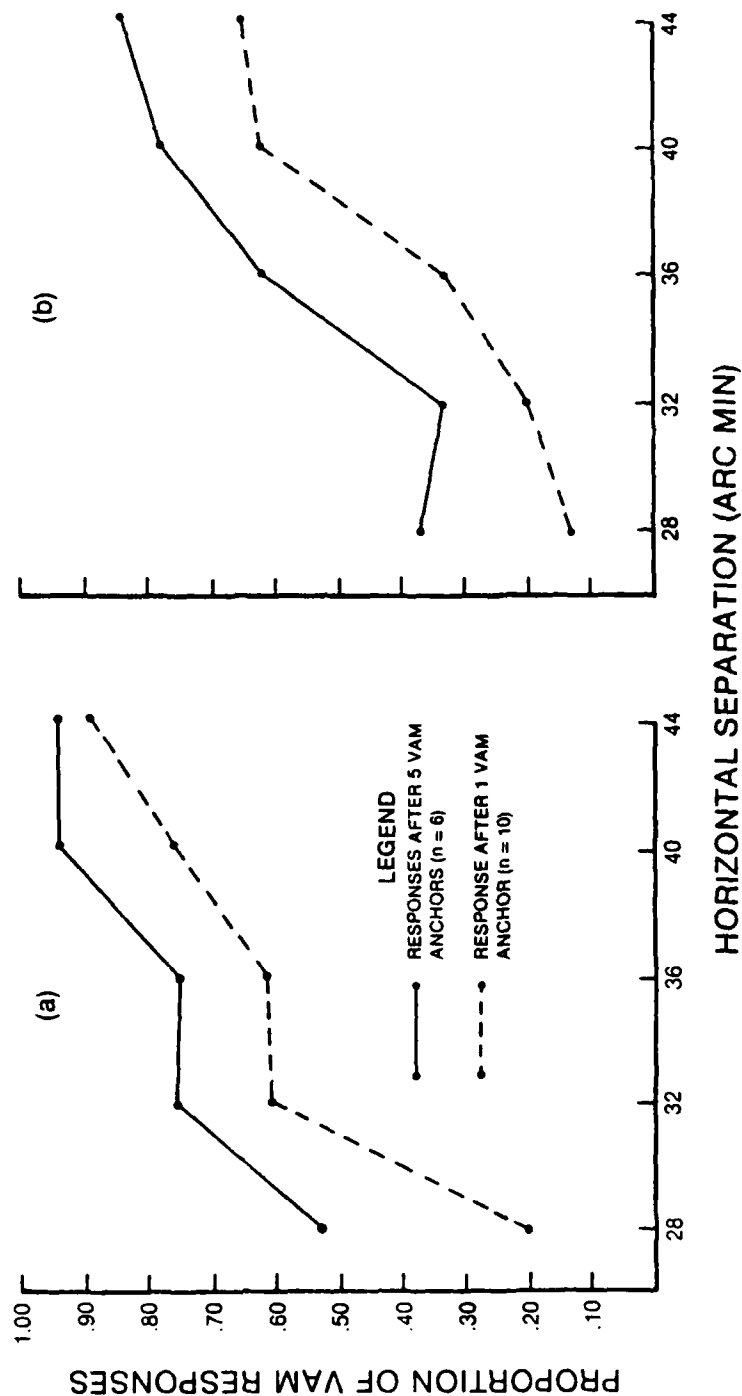


Figure 14. Proportion of Vertical AM (VAM) Responses as a Function of Horizontal Separation Between Elements in the 4-Dot Display [Responses to a display presented immediately after a VAM anchor are shown in (a), and responses to a display presented immediately after a HAM anchor are shown in (b).]

The data were partitioned into three factors: (1) a repeat ANCHOR (RANCHOR) variable (two levels), (2) a type of anchor variable (ANCHOR) indicating which anchor display (VAM or HAM) immediately preceded the test displays, and (3) a horizontal separation (HSEP) variable indicating the difference in spacing of dots in the 4-dot test configurations (five levels). The RANCHOR variable is a between-subjects factor while the remaining variables are within-subject factors. Therefore, a two (RANCHOR) by two (ANCHOR) by five (HSEP) mixed ANOVA design with repeated measures on the last two variables was used to analyze the VAM response data.

The variable of major concern in this analysis is the RANCHOR factor. Since none of the interaction effects proved to be statistically significant, the main effect attributable to RANCHOR can be assessed directly. This effect was found to be significant [ $F(1,14) = 5.675$ ,  $p < .05$ ]. As expected, the main effects for ANCHOR and HSEP were also significant [ $F(1,14) = 108.797$  and  $F(4,56) = 12.112$ ,  $p < .01$ , respectively].

The ANOVA indicates that five repetitions of the VAM anchor display reliably increased the proportion of VAM responses made to a subsequently presented test display. Thus, the mean separation between the repeat anchor and nonrepeat anchor data is significant.

Since the RANCHOR by ANCHOR interaction was not significant, it can be concluded that any difference between the VAM and HAM data sets across experiments is not reliable. That is, the repetition of the VAM

anchor had essentially the same magnitude of effect on the HAM data set as it did on the VAM data set.

Since the HAM anchor data were also elevated by the repeat VAM anchor manipulation, it can be concluded that the effects of anchors are additive, and the cumulative effect of repeating an anchor is not eliminated by a single anchor which induces a qualitatively different percept. Thus, prior correspondence induced by a repeated anchor survives the intervention of a qualitatively different percept (i.e., a series of VAM solutions survive beyond the correspondence problem offered by the HAM anchor display). Such a result means that the hysteresis remained operative after a different perceptual experience (i.e., the HAM percept). Based on our normal understanding of the meaning of hysteresis, such a result would not be expected. Its existence suggests that visual hysteresis can operate in a "long distance" or telegraphic mode.

Given the fact that the VAM anchor display was presented five consecutive times prior to a test display in Experiment IV, there obviously was a greater opportunity for the error of habituation to become operative in this experiment than was the case in Experiment III. Therefore, it could be argued that the difference in results across these experiments is not due to perceptual hysteresis alone, but rather is due to judgmental hysteresis (i.e., the error of habituation).

A response bias interpretation does not hold up under close examination. By definition, response habituation terminates when the following response is different from the immediately preceding response. Therefore, in this experiment the effects of habituation can extend only

over a relatively short string of trials, since the percept always changed when the opposing anchor displays were presented. If it is again assumed that habituation does not begin until more than two consecutive and identical responses are made, on average, there was no opportunity for habituation to extend over the HAM anchor, test display portion of a MIA cycle. During the course of the experiment, the error of habituation, if it occurred, would be manifested only over the five VAM anchors and the VAM test display portion of each cycle of the MIA paradigm.

To be consistent with a habituation effect, the VAM data set would have to show evidence of a higher proportion of VAM percept responses in this experiment relative to Experiment III, and the proportion of VAM responses in the HAM data set would have to remain constant across the two experiments. The data, as previously analyzed, do not support this prediction. It can be concluded, therefore, that the results of this experiment are not due to the error of habituation. Rather, the results are more consistent with the notion that a hysteresis-like effect operates at a perceptual level of information processing.

#### GENERAL DISCUSSION

The present series of four experiments focused on the issue of prior correspondence as a factor that plays an active role in the solution to a current correspondence problem. It was suggested that prior correspondence could be conceived to operate as a hysteresis effect, similar in nature to the hysteresis found in magnetic induction. Evidence in support of the hysteresis effect in the correspondence process

was found consistently across all four experiments. This held true even though two of the experiments (I and II) were performed within the context of an M of L paradigm and the other two experiments (III and IV) were performed within the context of a new psychophysical paradigm called the MIA procedure. Moreover, it was shown that the hysteresis effect could not be accounted for easily in terms of a response bias, or error of habituation concept.

#### The Correspondence Process and Motion Signal Processes

The 4-dot displays used to study the correspondence process induced a perception of motion. One way to solve a correspondence problem (i.e., a what-where connection), of course, is to add motion to a stimulus, or a set of them. Given this type of solution to the correspondence problem, there is a question of what motion mechanism(s) supply the movement signals. The results of Experiments I and II together point to the conclusion that only the long-range mechanism is involved in this type of solution to the correspondence problem. There was no unique change in the hysteresis effect when the spatio-temporal conditions of the 4-dot display satisfied the short-range mechanism requirements (16V condition), as opposed to when the requirements were not met (32V and 48V conditions). Since the long-range mechanism operates over the entire spatio-temporal range of values used in Experiments I and II, this mechanism must could have mediated the appearance of motion with the 4-dot displays.

It is important to distinguish the processes of motion signal analysis from the processes of a correspondence analysis of form

stimuli. Previous investigators have often intermixed the two concepts (e.g. Anstis, 1980; Ullman, 1979). Such a mixing of concepts has probably been a result of the fact that every demonstration of correspondence, including the present one, has used AM displays. A correspondence problem can be solved, however, without the incorporation of motion in the solution.

A motion picture, for example, presents a continuous series of correspondence problems, one after the other, as the film advances through the projector. A particular segment of frames may be of, say, a heated argument between the central characters in a "suspense thriller," against a living room backdrop. The backdrop may contain a sofa, game table, several chairs, and other articles of home furnishings. Even though these pieces of furniture do not change their relative position, with respect to each other, over successive frames, each item presents a correspondence problem. That is, the visual system still must match the sofa at time  $t_1$  with some object at  $t_2$ , the table at  $t_1$  with some object at  $t_2$ , etc. Solutions to these correspondence problems are obtained readily, as any movie-goer would attest--the sofa mates with a sofa, the table mates with a table, etc. Notice, however, that none of these solutions involves the perception of motion. Thus, although these may seem like trivial correspondence problems, they are correspondence problems nevertheless, and their solutions do not involve motion.

A third type of solution to a correspondence problem may sometimes be devoid of motion, while at other times it may induce a motion sensation. An object can appear to deform into another object. If a circle on frame 1 of a two-frame display is replaced by a concentrically

positioned square on frame 2, the circle will appear to elastically deform into a square, provided appropriate timing is used (Kolars, 1972). This correspondence problem is solved, therefore, by the addition of a short duration, local motion until a new shape is formed. Since object deformation generally, if not always, involves motion over at most a short distance, it may utilize the output of the short-range motion mechanism. Therefore, even though motion may be involved in this third type of solution to the correspondence problem, the solution may be qualitatively different from that found with the 4-dot display.

Another kind of shape deformation does not seem to induce a sensation of motion during the elastic change process. When a movie producer wishes to change smoothly from one scene to another, the film editor often uses the technique known as a dissolve. The technique involves reducing the luminance of one frame while simultaneously increasing the luminance of the second frame. This produces the effect of the shapes in the first scene emerging as new shapes against a new backdrop in the second scene. Thus, although several correspondence problems are solved over the scene one/scene two dissolve, no motion is induced in the process.

Although object deformation and object constancy have not been studied explicitly as problems in correspondence, it is reasonable to consider them from this perspective. If this viewpoint is valid, then motion processes and correspondence processes most surely are different, and they would be expected to follow different rules. The treatment of motion and correspondence as separate, but perhaps interrelated,

processes may help investigators to better understand the factors involved in perceptual organization.

### Percept Strength Model of Correspondence

The description of hysteresis offered to account for the behavior of magnetic induction utilizes the notion of force and force fields. A similar concept has been used by Gestalt psychologists in their analysis of perception. Gestalt theory concentrated on attractive forces as an explanatory concept (see Kolers, 1972). More contemporary Gestalt theory extended the force analysis to include forces of repulsion, as well (e.g., Brown and Voth, 1937). The concept of prior correspondence or hysteresis, however, was not incorporated into Gestalt theory, even though some recognition was given to the potential influence of prior experience (Wertheimer, 1923; Gottschaldt, 1926, 1929).

The present research has demonstrated the power of the hysteresis effect in a quantitative manner and, thus, suggests that a force model of perception could perhaps be developed beyond the level to which it has been taken by Gestalt psychology. An example of such an extension is the Percept Strength ( $P_S$ ) Model of the correspondence process. This model will be developed next.

The  $P_S$  Model of Correspondence begins with a set of axioms:

1. When information is acquired visually, the perceptual apparatus is confronted with a correspondence problem, since, after birth the new information is always preceded by other information.  
A solution to the immediate correspondence problem is realized

in conscious awareness as a complete entity. This entity is known as a percept (P).

2. Perception consists of an infinite set of percepts (birth to death) that change from (psychological) moment to moment.
3. Each potential solution to a correspondence problem (i.e., a percept) has associated with it a magnitude or strength. This strength is called Percept Strength ( $P_s$ ).
4. Each potential individual partnership that can be formed between stimuli across successive moments of time has associated with it a force of attraction. This force is called the force of correspondence ( $C_f$ ).

Consider a situation in which the total number of potential solutions to a current correspondence problem is limited to two. That is, the solution set for this correspondence problem is  $n = 2$ . An example of this situation is provided by the dynamic 4-dot display. The relationship between  $P_s$  and  $C_f$  with this display is characterized by the classical hysteresis loop as shown in Figure 15. In this illustration, a positive  $P_s$  is taken to represent AM in a vertical direction; a negative  $P_s$  is taken to represent a match that produces AM in a horizontal direction. As the magnitude of  $C_f$  is increased (positive polarity), the magnitude of percept strength,  $P_s$ , increases for a VAM percept until  $P_s$  reaches saturation. In like manner, as the magnitude of  $C_f$  is increased (negative polarity), the magnitude of  $P_s$  in favor of a HAM percept

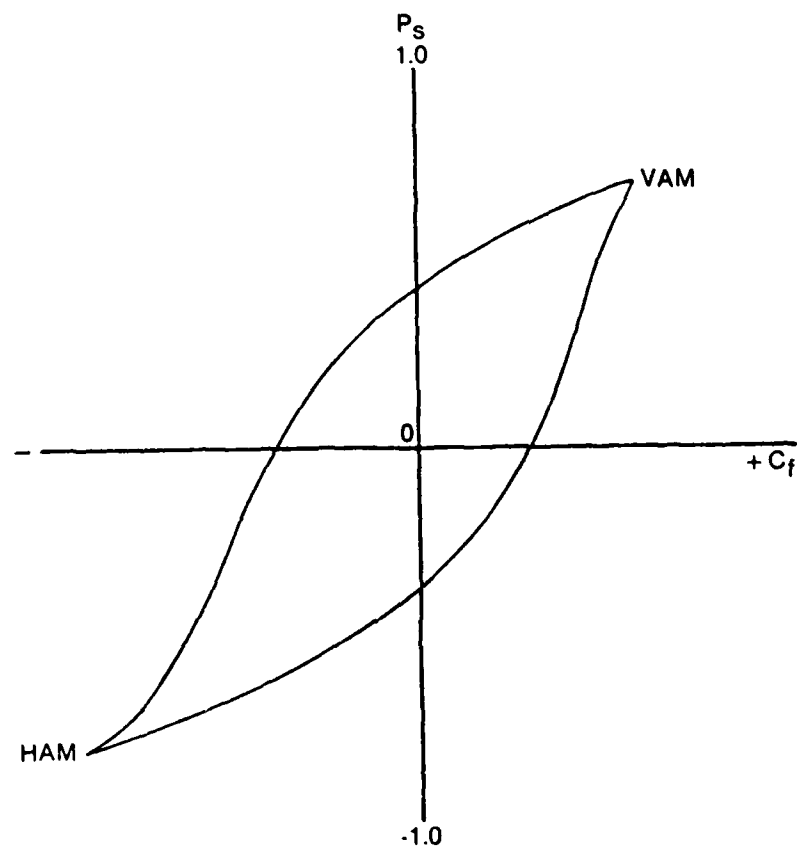


Figure 15. Relationship Between the Force of Correspondence ( $C_f$ ) and Percept Strength ( $P_s$ )--A Model of Hysteresis in Human Perception

increases until saturation is reached. Since the  $P_s$  for VAM ( $P_sV$ ) and the  $P_s$  for HAM ( $P_sH$ ) are reciprocally related,  $P_sH$  is expressed in Figure 15 as a negative  $P_sV$ .

Since a correspondence problem must always be solved, it is assumed that a VAM percept emerges if  $P_sV$  is positive, and a HAM percept emerges if  $P_sV$  is negative. But, due to the influence of prior correspondence, the functional relationship between  $C_f$  and  $P_s$  cannot be described by a single function.

Up to this point, the  $P_s$  Model of Correspondence is nothing more than a translation of the force model of induced magnetism to the realm of visual perception. The model is advanced further, however, by a set of three postulates that state which percept (P) will emerge as a function of the relationship between the  $P_s$  associated with a prior solution to a correspondence problem and the  $P_s$  associated with a current solution to a correspondence problem. The former  $P_s$  will be called residual  $P_s$ , and it will be represented by the symbol  $R^{P_s}$ . The latter  $P_s$  will be called current  $P_s$ , and it will be represented by  $C^{P_s}$ . The three postulates are:

1. If the net cumulative  $R^{P_s}$  is positive and the  $C^{P_s}$  is positive, then  $P = \text{VAM}$ .
2. If the cumulative  $R^{P_s}$  is negative and  $C^{P_s}$  is positive, then  $P = \text{VAM}$  if, and only if,  $|C^{P_s}|$  is greater than  $|R^{P_s}|$ , where  $|\cdot|$  indicates absolute value.

3. If the cumulative  $R^{P_S}$  is positive and  $C^{P_S}$  is negative, then  $P = \text{VAM}$  if, and only if,  $|C^{P_S}|$  is less than  $|R^{P_S}|$ .
4. If the cumulative  $R^{P_S}$  is negative and  $C^{P_S}$  is negative, then  $P = \text{HAM}$ .

NOTE: Which percept is identified as positive and which one as negative is, of course, purely arbitrary. Here, VAM has been treated as positive and HAM as negative.

A hysteresis effect can be derived from these three relationships. If, for example,  $R^{P_S V}$  is 10 units in strength and the current display yields a  $C^{P_S V}$  of -6 (i.e., by itself, it would induce a HAM percept), then the resultant percept (current problem) would be a VAM, even though the current information argues for a different solution to the correspondence problem. It is reasonable to assume that the strength of  $R^{P_S V}$  is changed after each percept formulation. For instance,  $R^{P_S V}$  for problem 1 and the  $R^{P_S V}$  for problems 2, 3, 4, and so on, are added to form the  $R^{P_S V}$  magnitude that exists immediately prior to some current correspondence problem. For the previous example, then, the new  $R^{P_S}$  would become 4 ( $10 - 6$ ) prior to the presentation of a new correspondence problem. If the same display is again shown, a new percept (HAM) will emerge this time since  $R^{P_S} + C^{P_S}$  would now equal -2 ( $4 - 6$ ). Thus, the exact same display configuration can yield conflicting percepts over time, depending on the state of  $P_S$  prior to the current presentation. This is a description of the hysteresis effect.

Given the proposition that  $R^{P_S}$  is changed after each percept by the latest  $C^{P_S}$  information, then it should be clear that such a change in  $R^{P_S}$  would result in a sizable hysteresis effect when a 4-dot display is altered in a step-wise manner, as in the M of L paradigm.  $R^{P_S}$  would continue to build in favor of the initial percept, say VAM, over trials. This would continue until the 4-dot display eventually induced a  $C^{P_S}$  of sufficient magnitude to counterbalance the  $R^{P_S}V$ . At that point, the percept would change to a HAM. If the process began with a HAM percept, the same resistance to change would be experienced, but now it would be in the opposite direction. Thus, the PTP from VAM to HAM and HAM to VAM would not occur at the same point.

The  $P_S$  model also correctly predicts a reduction in size of the hysteresis effect when the MIA paradigm is used. The  $R^{P_S}$  resulting from the opposing anchor displays would tend to cancel one another, since they should induce percepts of similar strength but with opposite polarity. Therefore, the effect of one anchor, say the VAM anchor, would essentially be effective only on the immediately following test trial, on average. By interleaving anchors, a progressive buildup of  $R^{P_S}$  in favor of a single percept is prevented or, at least, retarded. Consequently, the size of the hysteresis effect would be smaller with the MIA paradigm than with the M of L paradigm. This prediction from the  $P_S$  model is consistent with the results of Experiments I and III.

One outcome of Experiment IV is at odds with the commonly held notion of hysteresis. The results of that experiment imply that hysteresis has a telegraphic or "long distance" effect. This conclusion is based on the observation that the proportion of VAM responses was

elevated for test trials which were presented after (1) five VAM anchor trials, (2) one VAM data trial, and (3) one HAM anchor trial. What makes this outcome counter-intuitive is that the VAM hysteresis effect apparently persisted beyond an intervening HAM percept. Such a break in the consistency of a string of experienced percepts would normally be taken as evidence that hysteresis had terminated. This does not appear to be the case, however. The impact of the previous VAM percepts continued to affect the correspondence process beyond the HAM percept intervention. This seemingly illogical outcome can be accounted for, however, by the  $P_S$  model of prior correspondence. From the perspective of the  $P_S$  model, the  $R^{P_S}V$  immediately after a HAM anchor presentation in each MIA cycle would be a negative magnitude. That is, since the HAM anchor essentially always induced a HAM percept, the residual  $P_S$  after this experience must be biased toward a horizontal solution to the correspondence problem, which is indicated by a negative  $R^{P_S}V$  value. For a similar reason,  $R^{P_S}V$  immediately after a VAM anchor display presentation must be a positive value. If an MIA cycle is viewed to begin with a VAM anchor display, then the  $C^{P_S}$  generated by the following HAM anchor display must be of a magnitude to overcome (change the percept from vertical AM to horizontal AM) a positive  $R^{P_S}V$  when it is presented. Now, the HAM anchor display was the same in both Experiments III and IV; based on subject responses, it induced a HAM percept in both experiments. Because there were five VAM anchors per MIA cycle in Experiment IV and only one per MIA cycle in Experiment III, the  $R^{P_S}V$  would have a higher negative value after the HAM anchor presentation in the latter experiment, since the (negative)  $C^{P_S}V$  of the HAM anchor display would not have to overcome such a strong remaining (positive)

$R^{P_S}V$  as in the former experiment. Thus, even though  $R^{P_S}V$  is presumed to be negative after a HAM anchor display in both experiments, it is assumed to be more negative with the conditions of Experiment III than with the conditions of Experiment IV. Therefore, it would be predicted that responses to the test displays in the HAM data set (i.e., those presented immediately after the HAM anchor) would induce a higher proportion of VAM percepts in Experiment IV than in Experiment III. Furthermore, since  $R^{P_S}$  continues to change as more correspondence problems are encountered, the proportion of VAM percept responses to the VAM data set would be expected to be greater in Experiment IV, as well. These predictions are in agreement with the data from Experiments III and IV.

Although it has not been stated explicitly as a tenet of the  $P_S$  model, it is reasonable to assume that the strength of each solution, whether manifested or latent, to any given correspondence problem dissipates either as a function of time, or as a result of interference from the solutions to more current correspondence problems. That is, residual percept strengths ( $R^{P_S}$ ) are presumed to decay or otherwise be removed from the visual system, perhaps in a progressive fashion. This implies that even though there is a set of  $R^{P_S}$  for every "preceding" correspondence problem which could theoretically contribute to a prior correspondence effect for a "current" correspondence problem, the relative magnitude of these contributions would be reduced as the temporal distance between the current problem and each prior problem is increased. For the analysis of a prior correspondence effect, the  $R^{P_S}$  concept is treated as a reflection of the cumulative residual  $P_S$  prior

to a current target correspondence problem and, thus, would incorporate any change in magnitude due to dissipation, however achieved.

The Percept Strength Model of Correspondence provides a description of visual hysteresis, one that is consistent with the results of Experiments I through IV. Clearly, it has not been developed here to the point of being a comprehensive quantitative model of hysteresis. Several questions, such as the time course of hysteresis, the reduction, if any, in  $R^P_S$  due to disuse or interference, and others remain to be answered before a useful quantitative model of the hysteresis effect can be constructed.

#### The Method of Interleaving Anchors (MIA) Paradigm

It should be clear from the  $P_S$  model of hysteresis that in order to accurately assess the influence of prior correspondence on the correspondence process, it is necessary to maintain a comprehensive linear history of prior solutions to the correspondence problem. It is just this type of linear history that is built into the M of L paradigm. This is probably why hysteresis can be made manifest with the M of L technique. Unfortunately, the M of L procedure is inefficient and susceptible to response bias errors, and these problems limit its utility.

Outside of the M of L paradigm, virtually all other psychophysical paradigms employ some sort of randomization routine in their procedures, partly as a means to either eliminate or control response biases. The use of a random ordering of stimulus presentations makes it difficult to track the prior experience of the observer. Since such tracking is both

difficult and normally not considered to be an important aspect of research, it generally is not done. The result is that the influence of prior history becomes lost when most standard psychophysical paradigms are employed in research. Moreover, randomization and even counterbalancing schemes serve to equalize prior experience and, hence, in the process mask a hysteresis effect whenever it may exist. It was these shortcomings of current psychophysical procedures that led to the development of the MIA paradigm.

The theory behind the MIA paradigm was as follows: a visual display that always induces the same percept, apparently independent of prior events, was considered to be at or near a maximum  $P_S$  for that percept. As a result, its contribution to  $R P_S$  immediately before a test display was assumed to be dominant. Thus, to some degree, prior correspondence ( $R P_S$ ) could be functionally collapsed into a single anchor display presentation. It was presumed that the effects of prior correspondence which favored a particular percept would continue unabated unless the  $R P_S$  for that percept were neutralized in some way. The means of neutralization were expected to be accomplished by the presentation of a counter anchor display presented immediately after a test display. This display would have a maximum  $P_S$  for an alternate percept. Hence, in the two solution case, it would directly oppose the current  $R P_S$  and presumably cancel or reset it in the opposite direction. Thus, the functions of the anchor displays were (1) to allow prior correspondence to be preset to a known state, and (2) to allow the prior history of  $P_S$  to be controlled. Because it was believed that prior correspondence strength would be dominated by a contribution from an anchor display,

there was less of a necessity to track the order of presentation of each and every test display. Therefore, the test displays could be randomized as a means of eliminating the potential contamination by the error of habituation.

The efficacy of the MIA paradigm was demonstrated in Experiments III and IV. It seems to provide a relatively efficient means to investigate hysteresis in the domain of human perception. The results of Experiment IV indicate that care must be taken in the selection of anchor displays to insure they actually will balance out the effects of each other; otherwise, the extent of hysteresis will be under estimated, or in the extreme, it could go undetected. As used in this study, the subjects were required to respond to the anchor displays in the MIA paradigm. If it is certain the anchors have been properly selected, it may not be necessary to record the subject's responses to these displays. This would improve the efficiency of the MIA technique by reducing data collection time.

It should be obvious that the MIA paradigm is not limited to the investigation of hysteresis. Rather, it is a tool that can be used by any researcher who wishes to determine the relative strength of a sensory, perceptual, or cognitive event.

## Chapter II

### PRIOR CORRESPONDENCE AS A PRIMING EFFECT

In the study of hysteresis reported in the first chapter, the global form or structure of the correspondence problem over a  $t_3, t_4$  time interval was essentially unchanged from the global form of the prior correspondence problem that confronted the observer over a  $t_1, t_2$  time interval. In other words, a 4-dot display occupied both the  $t_1, t_2$  and the  $t_3, t_4$  time periods. A hysteresis effect, then, could be viewed as the impact of a prior solution to one 4-dot, two-frame display on the solution to a subsequently presented new 4-dot, two-frame display. It is important to know if the global similarity of a prior correspondence problem critically influences the solution of a following correspondence problem. It will be argued in this chapter that this global similarity is not essential for a prior correspondence effect to remain operative. Rather, it is proposed that only local similarities of structure over time are needed for prior correspondence to be realized. The presence of local similarities in the absence of a global one leads to a new type of prior correspondence effect called the priming effect. This will be followed by the presentation of four experiments on the priming effect. The first experiment will demonstrate the effect. The remaining experiments indicate how the priming effect is affected by changes in the spatio-temporal relationship between the prime and target segments of a set of test displays.

The anchor displays used in the study of the hysteresis effect were unique in that they nearly always led to the same solution to the correspondence problem. The HAM anchor display, for example, always induced a HAM percept. This means that even though there was a potential for the dots to pair up along the vertical path over the  $t_1, t_2$  interval, this potential was never realized as a percept. It could be argued, therefore, that the removal of this latter option from the set of solutions to the correspondence problem should not diminish a prior correspondence effect.

One alteration to the 4-dot display that preserves horizontal AM is shown in Figure 16. This display is made by simply eliminating the top row of dots in the 4-dot display. Now, if this new 2-dot display is presented immediately before a standard 4-dot display, will its solution (i.e., prior correspondence) impact the solution to the correspondence problem offered by the 4-dot display (see Figures 16a and 16b)? This is no longer a strict question of hysteresis, since there is no global structural similarity across the 2-dot and 4-dot displays. These two displays are locally similar, however, and both admit a horizontal AM solution to the respective correspondence problems. Under circumstances like this, the first display will be called a prime and the second display a target. The impact of the prime on the correspondence problem offered by the target display constitutes the priming effect.

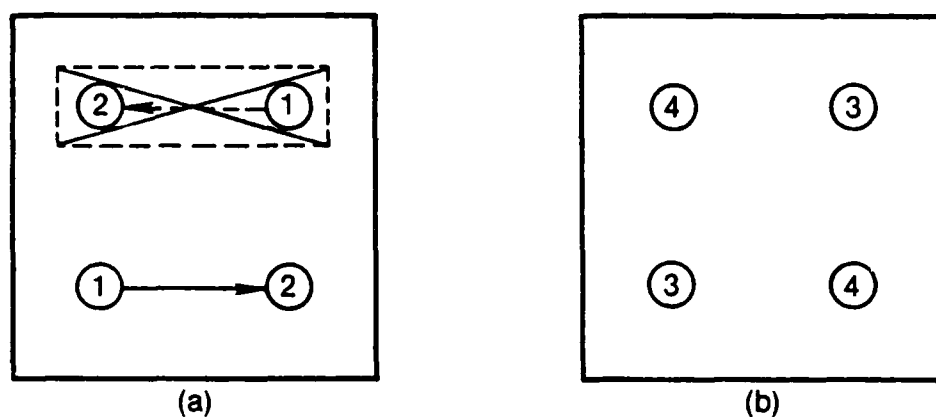


Figure 16. Illustration of a Sequential Prime-Target Display. (Panel "a" contains the 2-dot dynamic prime portion of the display. Panel "b" contains the 4-dot dynamic target portion of the display.)

#### EXPERIMENT V

The purpose of this experiment was to demonstrate the priming concept with the 6-dot display sequence shown in Figure 17. In contrast to the two displays shown in Figure 16, the 6-dot display represents an integration of the prime and the target displays into one. This was achieved by the spatial and temporal overlap of dots two and three (horizontal neighbors) in the 2-dot and 4-dot displays (see Figure 16). A second prime dot was included in the display as shown in Figure 17 (see dot 1). This dot served to add a second horizontal AM

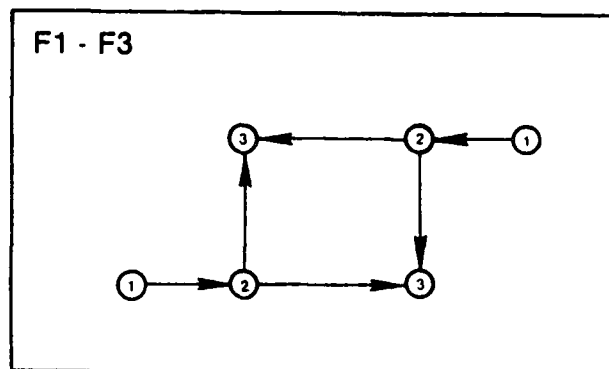


Figure 17. 6-Dot Dynamic Prime-Target Display

component to the prime display and, thus, should increase the saliency of the horizontal AM prime stimulus.

Consider the total correspondence problem offered by the 6-dot display. Review first the problem presented during the  $t_1, t_2$  interval. The problem has three possible solutions. Each dot at  $t_1$  can (1) mate with the nearest neighbor, (2) mate with the furthest neighbor, or (3) split and mate with both neighbors. These solutions yield: (1) horizontal AM, (2) diagonal AM, and (3) simultaneous horizontal and diagonal AM, respectively.

Next, review the correspondence problem presented over the  $t_2, t_3$  interval. This two frame portion of the 6-dot display is the familiar 4-dot display. It was shown previously that this correspondence problem can be solved in two ways: (1) mating between dots along the horizontal or (2) mating between dots along the vertical. It is important to note that dot pairs cannot form along the diagonal over the  $t_2, t_3$  interval. Now, it should be clear that if each dot 1 mates with the nearest

neighbor (follows the horizontal path), the t1,t2 2-dot display sequences are each analogous to that shown in Figure 16a and should serve to prime the HAM solution to the correspondence problem offered by the subsequent 4-dot target display segment. If, on the other hand, each dot 1 mates with its furthest neighbor, then the priming effect of these 2-dot sequences should not have any effect on the solution to the 4-dot correspondence problem since they would not prime either the VAM percept or the HAM percept. In summary, it is predicted that the 2-dot portion of the 6-dot display will either increase the proportion of HAM percepts realized by the 4-dot portion of the display, or it will have no effect on the way the 4-dot correspondence problem is solved.

### Method

#### Subjects

Six undergraduate students with normal or corrected-to-normal vision served as subjects. All of them were naive about the purpose of the experiment and were inexperienced as psychophysical observers.

#### Apparatus

Display generation, trial sequencing and control, and response recording were accomplished in the same manner described in Experiment III. The MIA psychophysical paradigm was employed. As before, VAM and HAM anchor displays consisting of 4-dot configurations were utilized. The vertical dot separation for all displays was fixed at 48 arc minutes. The horizontal separation for the VAM anchor was 60 arc minutes, while it was only 12 arc minutes for the HAM anchor. Display

timing was the same as that used in Experiment III. Five test displays were randomly selected for presentation before and after each anchor display presentation. Each of these displays consisted of three frames that contained the 6-dot pattern shown in Figure 17. The spatial separation between the dots on f1 and those on f2 (nearest neighbor) was held constant at 12 arc minutes. The t1,t2 time interval was fixed at 31.17 msec. The vertical distance between the f2 and f3 dots was maintained at 48 arc minutes. As before, five horizontal separations between the f2,f3 dots were used. These separations were identical to those used with the basic 4-dot display in Experiment III. For convenience, those test displays will be referenced by their f2,f3 dot separation (e.g., H28, H32, etc.). The t2,t3 time interval was also fixed at 31.7 msec. As before, each frame for all of the displays used in the experiments was exposed for 185.5 msec.

#### Procedure

The experimental procedure followed the structure of Experiments I through III. Each subject participated in one 60-minute testing session consisting of three parts: familiarization, practice, and experimentation. The training displays described in Experiment I were again employed during the familiarization phase. In addition, a third training display was included. This third display was simply a modification of the original training display consisting of frames A2, B, and C (see Figure 5). It will be recalled from Experiment I that with frame A1 in the display a HAM percept always emerged. The dot pattern in this familiarization sequence, therefore, was identical in form to the 6-dot test display. The modified version of this display contained the same

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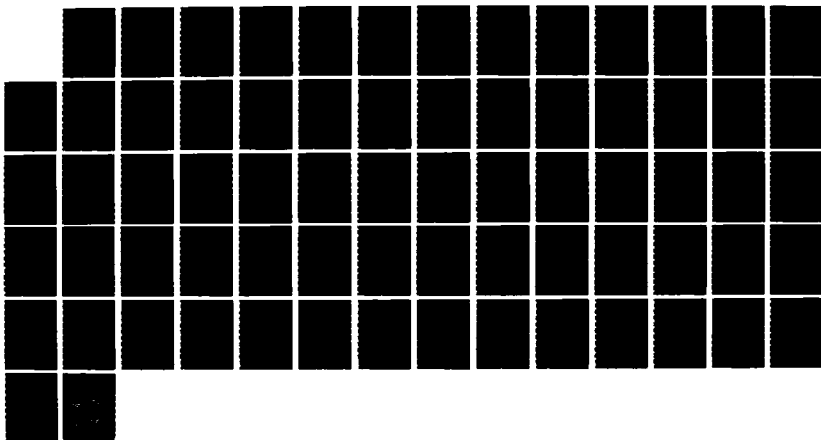
APPARENT MOTION AND PRIOR CORRESPONDENCE EFFECTS IN  
VISUAL PERCEPTION(U) HARRY G ARMSTRONG AEROSPACE  
MEDICAL RESEARCH LAB WRIGHT-PATTERSON AFB OH  
R G EGGLESTON JUN 86 AAMRL-TR-86-027

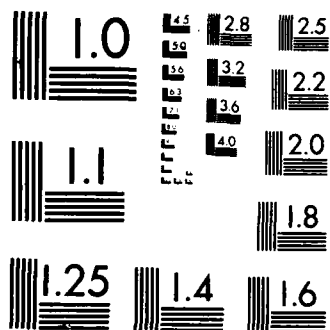
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MICROCOPY RESOLUTION TEST CHART  
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6-dots, but the horizontal displacement of the dots on frame A1 was greatly increased (about 2 degrees of visual angle) relative to those on frame B. Given the larger dot separation of this third display, it induced a new percept that consisted of an initial horizontal AM between the dots across frames A1 and B, followed by a vertical AM between the dots across frames B and C. The familiarization phase commenced with a single presentation of each of the three training displays (TD). The subject verbally reported the type of motion perceived with each display. These descriptions were then reduced by the experimenter into the terms (1) horizontal motion, (2) vertical motion, and (3) vertical II motion (horizontal motion followed by vertical motion). Each display was then presented three or four more times, and the subject was instructed to report his AM percept by using one of the labels provided. All subjects were able to reliably discriminate among the three types of AM percepts.

A practice session followed familiarization training. The purpose of this session was to acquaint the subject with the display presentation and response recording procedures to be used in the experimentation phase. These procedures were the same as those employed in Experiment III, with the exception that the subject was to make a vertical joystick response to indicate both a vertical AM percept or a vertical II AM percept. Thus, the instructions biased the subjects toward a vertical joystick response any time a vertical AM percept was experienced, even if it was preceded by a horizontal AM percept in the same display. (This was the reason why the vertical II label was used in the familiarization phase.) Practice continued until the subjects could

reliably operate the display presentation-response recording equipment, and it was always terminated with either a VAM or a HAM anchor display presentation.

The VAM and HAM anchor displays and the five 6-dot test displays were used in the experimental session in accordance with the MIA paradigm. Independent random schedules were used to order the test display presentation after each type of anchor display. Randomization was constrained such that each test display was presented an equal number of times. Therefore, one sequence through the MIA paradigm was as follows: (1) 4-dot VAM anchor, (2) 6-dot prime-target test display, (3) 4-dot HAM anchor, and (4) 6-dot prime-target test display. A 2-minute rest break was provided after 15 cycles of the MIA presentation sequence had been completed. The experiment was terminated at the completion of an additional 15 MIA cycles. Thus, each subject made 60 responses to each anchor display and six responses to each of the five test displays. As in all previous experiments, testing was conducted in a self-paced manner after the subject was fully dark-adapted to the ambient illumination conditions.

### Results and Discussion

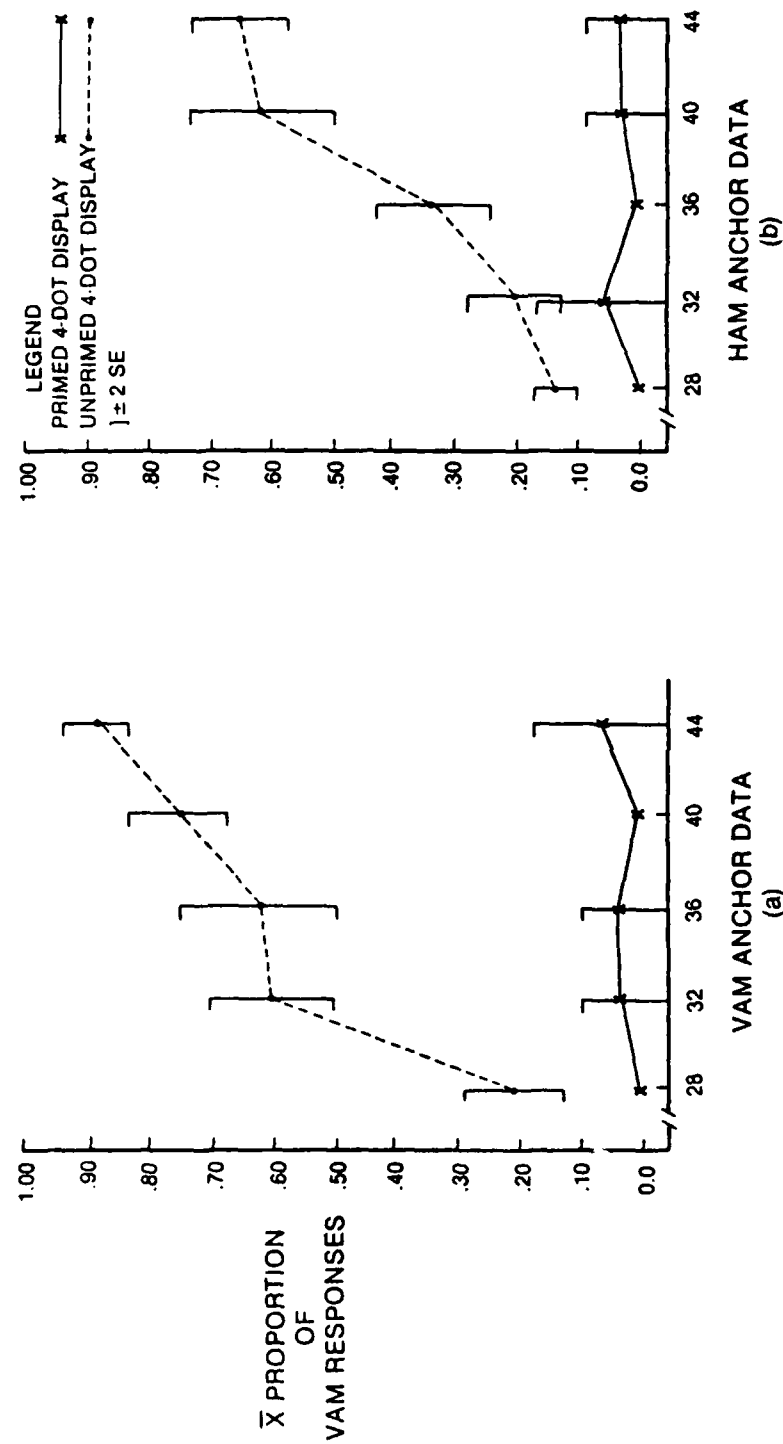
To facilitate discussion, the  $t_1, t_2$  portion of the 6-dot test display will be called the prime display. The  $t_2, t_3$  portion of the same display will be called the target display. The target display, therefore, is the same as the 4-dot display used in the earlier study of hysteresis. When the total three-frame ( $t_1, t_2, t_3$ ) 6-dot display is treated as a unit, it will be called the test display.

Since each 4-dot target display admits both a VAM and a HAM percept, it is necessary to establish a base rate of occurrence for each of these percepts in order to assess the priming effect. The data from Experiment III can be used to fix the base rate. Specifically, the proportion of VAM percept responses to the five target displays presented immediately after a VAM anchor provide a base rate for the solution to the correspondence problem when perception has been biased to favor a VAM percept. Likewise, the proportion of VAM percept responses to those target displays presented immediately after a HAM anchor display provide a base rate for the solution to the correspondence problem when perception has been biased to favor a HAM percept. In short, each leg of the hysteresis loop described in Experiment III defines the expected rate of occurrence of a VAM percept under known conditions of a given percept bias. Consequently, the VAM data and HAM data of Experiment III will be used here as a baseline control condition.

With respect to both sets of control data, it is predicted that the inclusion of a 2-dot prime display prior to the target 4-dot display will increase the proportion of HAM percepts elicited by the 6-dot test display.

The pattern of responses was the same for all six subjects; therefore, only mean data will be reported.

Figure 13 clearly shows a reduction in VAM responses for both the VAM and HAM data sets under the priming condition. In fact, for all intents and purposes, priming reduced VAM percepts practically to zero



### HORIZONTAL DOT SEPARATION (ARC MIN) IN TEST DISPLAYS

Figure 18. Mean Proportion of VAM Responses as a Function of Horizontal Dot Separation (4-Dot Display)

for all five test displays. No attempt was made to statistically confirm the reliability of the priming effect because of its large magnitude.

The VAM and HAM anchor displays employed in Experiment III were also used in this experiment. The inclusion of these anchor displays insured that the appropriate bias conditions did, in fact, exist prior to the presentation of each 6-dot test display. Since these were the same anchor displays as were used in Experiment III, the comparison of VAM responses across the unprimed (Experiment III) and primed conditions is valid.

As before, the anchor displays were generally successful in setting the percept to the desired state. The VAM anchor induced a VAM percept 88.9 percent of the time; the HAM anchor induced a HAM percept 100 percent of the time. This compares with 96.7 percent and 97.7 percent, respectively, for Experiment III. Thus, the responses to the HAM anchor were essentially identical across experiments. There was, however, about a 5 percent reduction in VAM responses to the VAM anchor in the present experiment. A 5 percent reduction may not seem significant at first glance, even though a  $t$ -test attests to its statistical reliability ( $t = -2.14$ ,  $df\ 14$ ,  $p < .05$ , one tail test). But, after the first trial each VAM anchor display was itself preceded by a prime-target display sequence (i.e., from the preceding MIA cycle) that induced a HAM percept more than 90 percent of the time. It is possible that this prior correspondence encouraged more than the expected number of HAM responses to the VAM anchor display. Indeed, the sheer magnitude of the

priming effect on the target displays (see Figure 18) makes such an interpretation reasonable.

The results of this experiment show in dramatic fashion the power of the priming effect in the correspondence process. Even 4-dot target displays that induced a VAM percept with a base rate of about 90 percent (44H display) were forced by virtue of an antagonistic prior correspondence (i.e., the two dot prime display) to induce a HAM percept essentially all of the time.

The priming portion ( $f_1, f_2$ ) of the test display is similar to the classical AM display used since the time of Wertheimer. The only difference is that two 2-dot displays were simultaneously presented. It has long been known that AM with a simple 2-dot, two frame display is not experienced if the time between frames (or the stimulus onset asynchrony) is either too long or too short. The temporal boundaries between the perceptions of simultaneity, AM, and succession, however, are relative and depend on the intensity of the stimuli and their spatial displacement (see Kolers, 1972, for a review). Thus, it might be expected that the magnitude of the priming effect can be varied by appropriate spatio-temporal manipulations of the 6-dot display. In the next experiment, the horizontal separation between dots 1 and 2 of the 6-dot display was increased to 120 arc minutes from the 12 arc minutes used in this experiment. Six new subjects were used; in all other respects, Experiment VI was identical to the present one. It was expected that this spatial manipulation would weaken the priming effect, and there would be an increase in the proportion of VAM percepts elicited by the target display.

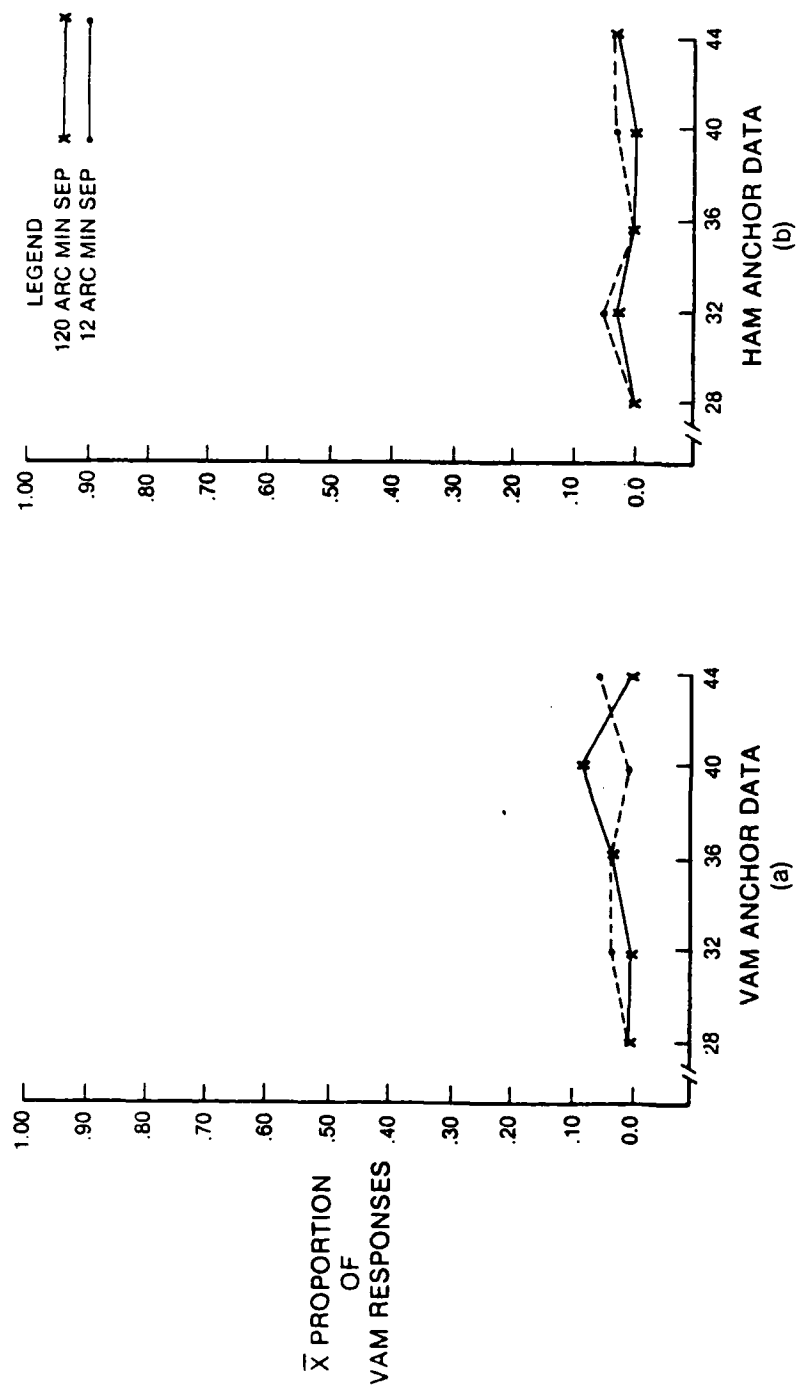
## EXPERIMENT VI

Results and Discussion

The proportion of VAM responses to the five test displays was calculated separately for (1) the set of test displays presented immediately after the VAM anchor display (VAM data set), and (2) the set of test displays presented immediately after the HAM anchor display (HAM data set). Since the pattern of responses was the same for all subjects, only mean data are reported. The results are shown in Figure 19, along with comparison data from Experiment V.

There was essentially no difference in the response data across the two experiments. The priming display was maximally effective (i.e., induced a HAM percept) across all five test displays (see Figure 19). This held true for both the VAM and HAM data sets. Therefore, the predicted increase in VAM percept responses was not confirmed. No attempt was made to statistically verify the nonsignificant results, as the overlap between the present data and that from Experiment V is obvious by inspection of Figure 19.

The change in prime-target dot separation from Experiment V was 108 arc minutes (120 - 12). This is a substantial change; therefore, it was quite surprising that the magnitude of the priming effect was not reduced with this spatial manipulation. This negative result could simply be due to insensitivity of the experiment caused by a "floor effect" in the data, or it might be the result of a priming effect which is a curvilinear function of horizontal dot separation, and only points on the ends of the function were checked by these two experiments. To rule



HORIZONTAL DOT SEPARATION (ARC MIN) IN TEST DISPLAYS

Figure 19. Mean Proportion of VAM Responses as a Function of Horizontal Dot Separation (4-Dot Display)

out this latter possibility, an informal experiment was conducted that used four horizontal dot separations between the prime and target segments of the 6-dot display. These separations spanned the distance between 12 and 120 arc minutes. The actual separations were: 120, 44, 36, and 12 arc minutes. The author was the sole subject in this experiment. The results were essentially the same across all four prime-target dot separations, and mirrored those shown in Figure 19. Therefore, it is likely that the priming effect is not a curvilinear function of dot separation over the spatial range investigated.

As before, responses to the VAM and HAM anchor displays were also collected in the main experiment. The results were essentially the same for five of the six subjects. The mean ( $n = 5$ ) percentage of VAM percepts to the VAM anchor was 88.0 percent while the mean ( $n = 6$ ) percent of HAM percepts to the HAM anchor was 97.7 percent. The percentages are essentially the same as those found in the last experiment.

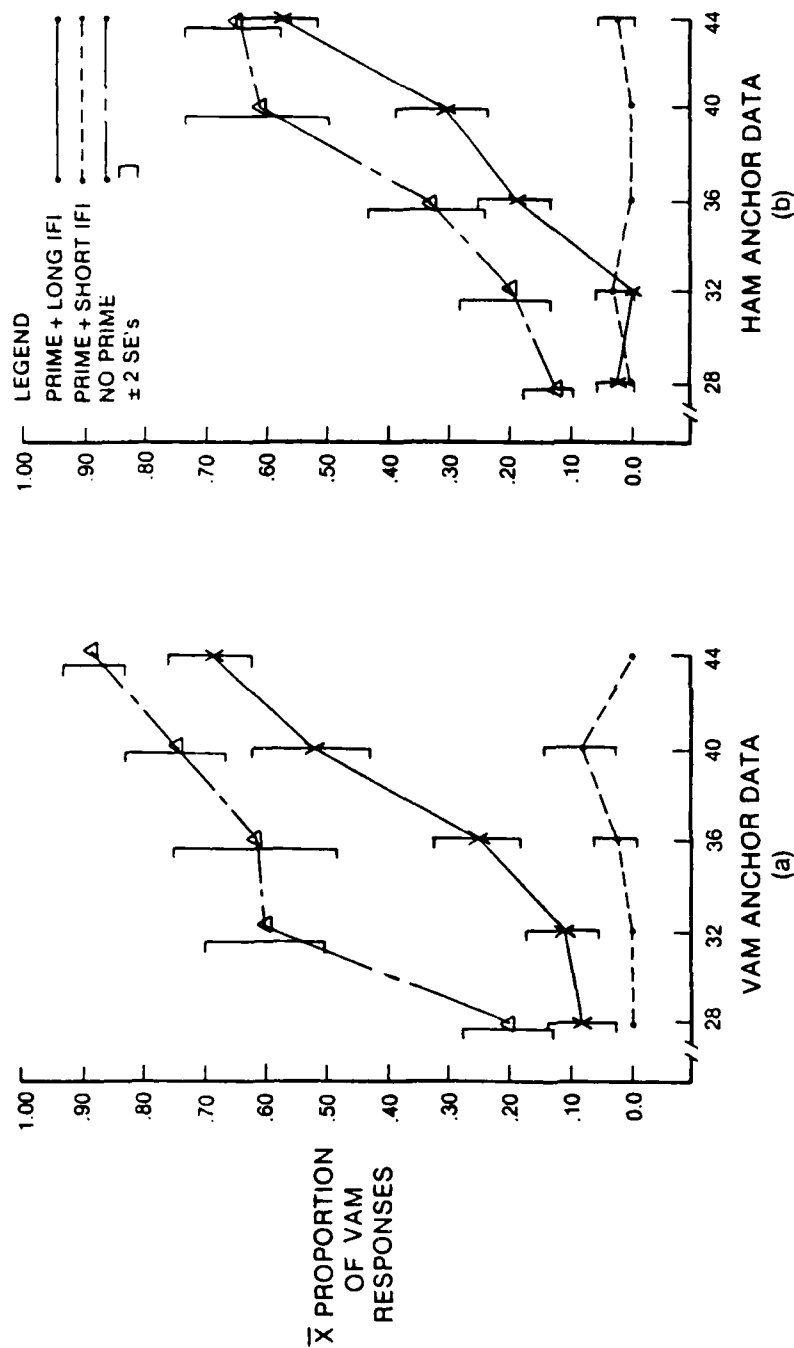
The VAM anchor display induced a VAM percept only 60 percent of the time for the atypical subject. (If these data are included with the other subjects, the mean VAM response drops to 83.3 percent.) It is not clear why one subject would show such a sizeable reduction in VAM percepts with the VAM anchor display. It could be an indication, however, that the priming effect was of such a magnitude that it carried over to each subsequent VAM anchor display, a display known to normally induce a VAM percept.

## EXPERIMENT VII

The 2-degree prime-target spatial separation employed in the last experiment was the maximum that could be achieved with the experimental set-up. Therefore, attention was turned next to a temporal display parameter as a means to moderate the priming effect, since all AM percepts are affected by temporal as well as spatial manipulations. Preliminary research revealed that for a spatial distance between the prime and target dots of 2 degrees or less, the priming effect remained at a maximum level even when the inter-frame-interval (IFI) which separated the prime and target portions of the test display was lengthened to the point (about 500 msec) where there was no sensation of AM between the prime dots and the target dots. The priming effect did appear to weaken, however, when the prime-target IFI was set at about 1000 msec. Accordingly, this value was selected for use in the experiment. The experiment was identical in every detail to Experiment VI, except for the increase of the prime-target IFI from 31.17 msec to 1000 msec. Six new subjects served as observers for the experiment.

### Results and Discussion

The results of the experiment are shown in Figure 20. As before, the proportion of VAM percept responses (mean data) is portrayed as a function of the horizontal dot separation of the five test displays (target portion). Comparison data from Experiment VI (short IFI) and Experiment III (no prime) are also shown in Figure 20.



### HORIZONTAL DOT SEPARATION (ARC MIN) IN TEST DISPLAYS

Figure 20. Mean Proportion of VAM Responses as a Function of Horizontal Dot Separation (4-Dot Display) (X = no prime,  $\Delta$  = prime + long IFI, and 0 = prime + short IFI)

Consider first the VAM anchor data set (Figure 20a). The results of this experiment fell almost exactly midway between those of Experiment III (no prime) and Experiment VI (prime with short IFI). The same relationships hold also for the HAM anchor data set (Figure 20b). The prime-with-long-IFI curve (Experiment VII) was in every case below that of the no-prime curve (Experiment III). The distance between the two curves for both data sets reflects the impact of the horizontal AM prime on the solution to the subsequent correspondence problem. The elevation of the prime-with-long-IFI curve relative to the prime-with-short-IFI curve reflects the reduction in the priming effect caused by the longer temporal delay between the prime and target segments of the test display.

It is clear from the figure that the separation of the three functions for each data set is significant; therefore, a statistical analysis of the data was not performed.

There is a suggestion of a hysteresis effect in the data from the present experiment. This can be seen by directly comparing the HAM data set with the VAM data set (see Figure 20). To facilitate such a comparison, these data have been redrawn in Figure 21. The separation in the VAM and HAM data curves is in the proper direction for a hysteresis effect. A 2 x 5 repeated measure ANOVA was performed on the response data to assess the significance of the hysteresis effect. The two factors were: (1) horizontal dot separation in the target portion of the test display (HSEP) (five levels), and (2) type of preceding anchor display (ANCHOR) (two levels). The main effect for both factors was significant [ $F(1,5) = 4.81$ ,  $p < .05$  (one tail) and  $F(4,20) = 27.17$ ,

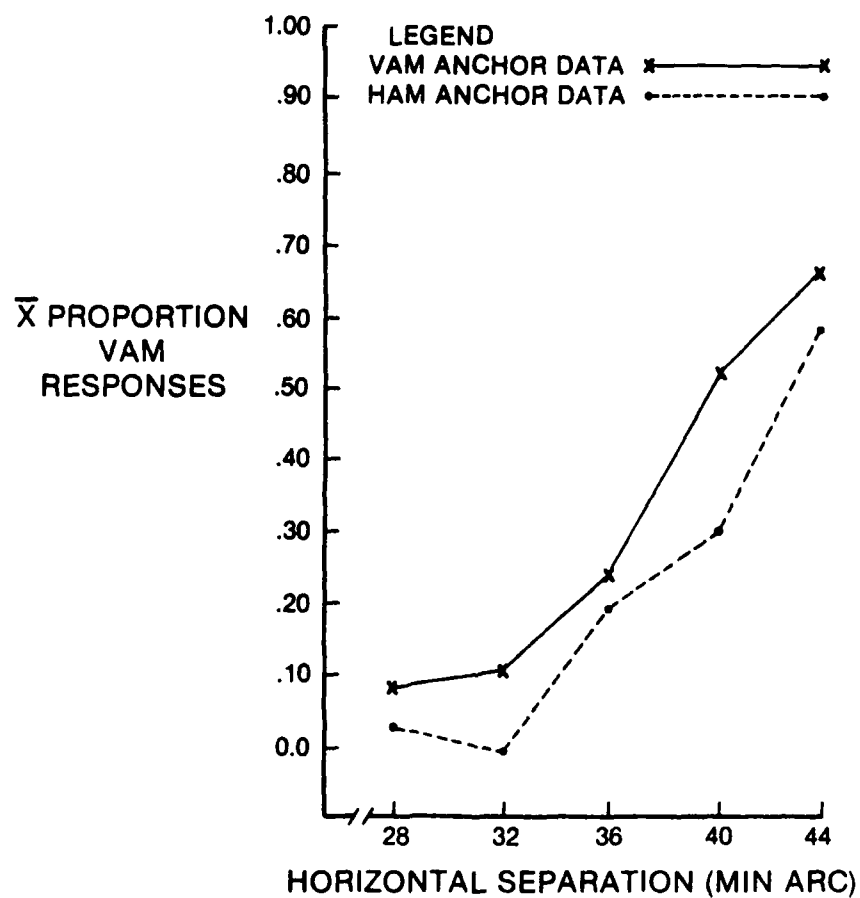


Figure 21. Mean Proportion of VAM Responses as a Function of the Horizontal Dot Separation (4-Dot Display)

$p < .01$ , respectively]. The ANCHOR by HSEP was not significant [ $F(5,20) < 1.0$ ]. Thus, there is statistical confirmation of the reliability of the hysteresis effect.

It is clear from the results that prior correspondence can affect the correspondence process simultaneously through the means of the hysteresis effect and the priming effect. In this experiment, as in Experiment IV, the hysteresis effect was of a "long distance" nature, in that a prior presentation of a VAM anchor apparently affected the solution to the correspondence problem offered by the target segment of a subsequently presented test display, even after an intervening correspondence problem (priming segment of the test display) had been solved in a manner that conflicted with both the solution to the VAM anchor display and the target display. This provides another indication that the residual influence of prior correspondence is maintained for more than a single preceding event.

#### EXPERIMENT VIII

In Experiments V through VII the spatio-temporal relationship between the prime and target displays was manipulated. The magnitude of the priming effect remained at a maximum level over the range of spatial separations that were permitted by the experiment (see Experiments V and VI). An increased temporal separation (Experiment VII) between the prime and target displays, however, proved to reduce the strength of the priming effect, although it was not sufficient to eliminate the effect altogether. In the experiment described next, a new manipulation was used in an effort to reduce the magnitude of priming. The procedure was

identical to that employed in Experiment IV in the last chapter. One anchor display, the VAM anchor, was repeated several times in succession before a test display was presented. Based on the results of Experiments IV and VII, there is reason to believe that prior correspondence effects are extensive in time, and include the contributions of more than the solution to a single correspondence problem, independent of the form (hysteresis or priming) of the problems involved. If the extensive nature of prior correspondence holds even when the correspondence problem involves an anchor display, then the repetitive presentation of such a display should yield a buildup of the strength of the percept it induces. (Naturally, an increase in percept strength could occur only if a single presentation of the display did not drive the strength function to true saturation.)

The purpose of the experiment was to see if the strength of the priming effect (horizontal AM) could be reduced by the inclusion of five successive VAM anchor presentations in each cycle of an MIA paradigm. (Only one HAM anchor display was presented per MIA cycle.) The test and anchor displays were the same as those used in Experiment VI.

The spatial separation between the prime display and the target display was 120 arc minutes. The prime target IFI was 31.17 msec. The horizontal separation between dots in the target displays was either 28, 32, 36, 40, or 44 arc minutes. As always, the vertical separation of test dots was held constant at 48 arc minutes. Six new subjects served as observers in the experiment.

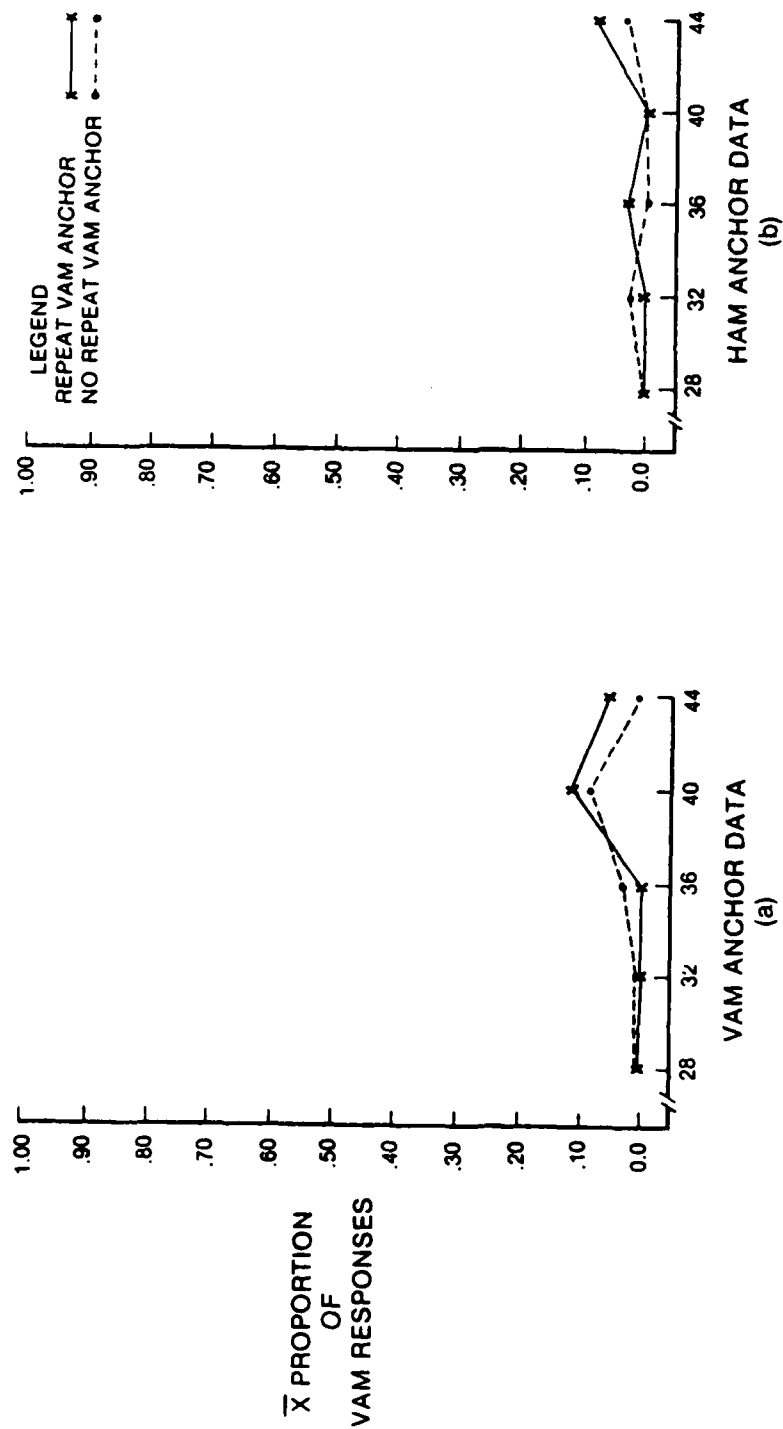
## Results and Discussion

The mean proportion of VAM percept responses to each of the five test displays are shown in Figure 22. Separate curves are shown for responses to test displays (1) presented immediately after five VAM anchor displays (Figure 22a), and (2) presented immediately after a HAM anchor display (Figure 22b). Comparable data from Experiment VI are also provided in the figure for the purpose of comparison. To facilitate the discussion, the data from the present experiment will be referred to as repeat anchor data, and the Experiment VI data will be referred to as the nonrepeat anchor data. There are, of course, VAM and HAM data subsets in both the repeat anchor and nonrepeat anchor data arrays.

It is clear from Figure 22 that there is no difference in the proportion of VAM responses to the test displays between the repeat anchor and nonrepeat anchor conditions.

The proportion of VAM responses to the VAM anchor and HAM anchor displays in the repeat anchor condition was 98.2 percent and 0.0 percent, respectively. For the nonrepeat anchor condition, these percentages were 83.3 percent and 0.0 percent, respectively. A nonrelated t-test indicated that the difference of VAM responses to the VAM anchor display was significant ( $t = -2.533$ ,  $df\ 10$ ,  $p < .025$  one-tail test). This indicates that the repeat anchor manipulation apparently increased the strength of the VAM percept.

The results of this experiment can be viewed in at least two ways. First, the correspondence problem offered by the target 4-dot



### HORIZONTAL SEPARATION (ARC MIN)

Figure 22. Mean Proportion of VAM Responses as a Function of Horizontal Dot Separation (4-Dot Display)

display can be treated as being influenced by two separate types of prior correspondence biasing effects. One of these is the priming effect produced by the solution to the 2-dot correspondence problem. The other is the hysteresis effect produced by the solution to the 4-dot VAM anchor display. From this perspective, the repeat anchor manipulation did not increase the impact of the hysteresis effect on the solution to the target correspondence problem. The impact of the priming effect remained at the same level as when no repeat anchors were used, a level that still precluded the assessment of a spatial distance manipulation because of a "floor effect."

A second view of the experiment does not emphasize the apparent difference in the prior correspondence problem offered by the VAM anchor and prime displays. Rather, it emphasizes the number and temporal sequencing of events (correspondence problems) that occur prior to each target correspondence problem. Given the structure of the MIA paradigm, the 2-dot (prime) correspondence problem always immediately preceded the target problem, whereas the 4-dot (VAM anchor) problem was always once-removed from it. Therefore, horizontal AM priming was the most recent solution to a correspondence problem prior to the presentation of a target problem. But since the VAM anchor was repeated five times in succession, a VAM solution to the correspondence problem was experienced more frequently in the near past relative to the 4-dot target problem. Thus, the experiment could be viewed as a test of the relative importance of the recency of a solution to a correspondence problem versus the frequency of a set of such solutions on the solution to a subsequent correspondence problem. From this perspective, the data support the

conclusion that a recent prior correspondence outcome has a greater effect on the selection of a solution to a subsequent correspondence problem than does the frequency of a particular prior correspondence outcome.

The increase in the proportion of VAM responses to the VAM anchor display from the no repeat anchor condition to the repeat anchor condition indicates that the strength of the VAM percept is not at a maximum after only a single anchor display presentation. This may be because the VAM anchor correspondence problem itself is affected by prior correspondence in the MIA paradigm. For instance, the VAM anchor can be treated as a "target" display. Beginning with the second MIA cycle, the VAM anchor is always preceded by two test displays and a HAM anchor display. In this experiment, each one of these three "prior correspondence" problems nearly always induced a HAM percept (see Figure 22). Accordingly, the correspondence process would be biased to favor a HAM percept at the time the VAM anchor was presented. Thus, the VAM percept generated by the VAM anchor display would have to overcome the HAM bias before a VAM percept could emerge. The impact of the three HAM-biased "prior correspondence" problems would be reduced when the VAM anchor display was repeated five times, since each repetition of the anchor display would represent a new "prior correspondence" problem that favored the VAM percept. Therefore, as the data show, the proportion of VAM responses to the VAM anchor should be higher in the repeat anchor condition.

## GENERAL DISCUSSION

The experiments reported in this chapter clearly demonstrated that prior correspondence, in the form of a priming effect, had a significant influence on the solution of an immediately following correspondence problem. This result held true for two widely different spatial and temporal separations between elements of the prime display. In addition, experiment VII showed that both the hysteresis effect and the priming effect could affect simultaneously a single current correspondence problem, and all of the experiments indicated that the relative impact of the priming effect was greater than that of the hysteresis effect. The following discussion attempts to elaborate and interpret these results (1) in light of the findings presented in Chapter I, and (2) from the general perspective of a correspondence model of visual perception.

### Relationship Between the Hysteresis and Priming Effects

The terms global and local were used in the introduction to Chapter II to distinguish between the hysteresis effect and the priming effect. The distinction between the two phenomena was made on the basis of the structural similarity of the prior correspondence problem to the current correspondence problem. Upon closer inspection of the experiments, it is clear that when both the prior and current correspondence problems involved 4-dot displays (i.e., the hysteresis effect), these problems shared at least three properties: (1) an identical global stimulus pattern (structure), (2) a high degree of spatial overlap of the stimulus pattern space, and (3) the same solution set for both

correspondence problems. When the prior correspondence problem involved a 2-dot display (i.e., the priming effect), the similarities between the prior and current correspondence problems were somewhat less. The 2-dot and 4-dot displays were only locally similar (i.e., both contained a small number of dots); there was little spatial overlap of the stimulus patterns across problems; and the solution set of the prime display was only a subset of those available in the target display.

One might expect the impact of prior correspondence to be at its greatest when the similarity between the prior and target problems is high, and to be at a minimum when such similarity is low. Thus, the magnitude of the hysteresis effect would be predicted to be greater than the magnitude of the priming effect. The results of the reported experiments, however, do not support this prediction. To accord well with the prediction, the proportion of VAM percept responses to a test display presented immediately after a VAM anchor display would have to be relatively high across all of the test displays used, since each test display was quite similar to the prior VAM anchor display. Likewise, the proportion of VAM percepts would have to be relatively lower for responses to each target display shown immediately after a HAM anchor display. Finally, the proportion of VAM responses to a target display shown immediately after a prime display would be expected to be intermediate between the results when the VAM and HAM anchor served as the prior correspondence problems. A comparison of the results across Experiments III through VIII indicates that these predictions were not supported. It can be concluded, therefore, that a high degree of similarity between prior and current correspondence problems is not

essential for the prior problem to influence, perhaps even control, the solution to the current one.

#### Interaction Between Types of Solutions to a Correspondence Problem

As stated earlier, if an object is viewed over a relatively long time period, it may appear to (1) remain stationary and retain its present shape, (2) remain stationary and change shape, (3) move and retain its shape, or (4) move and change shape. From the view of correspondence theory, each of these percepts represents a qualitatively different type of solution to a correspondence problem. These types of solutions pertain equally as well to an entire array of stimuli, or scene, as they do to a single object. It has been shown in the present study that the selection of a particular solution to a correspondence problem is influenced by an exposure to an earlier correspondence problem. In the problems used to demonstrate the hysteresis effect, the type of solution was the same for the prior and current correspondence problems. One might ask whether or not a prior correspondence effect would result if there were a qualitative difference in the type of solution to prior and current problems.

Although the experiments in this study were not designed to address this issue, the results of Experiment VII provide some insight into the matter. In that experiment, a 1 second IFI was used to temporally separate the prime and target displays. Such an IFI is well beyond the limit for AM with the spatial separation between dots used in the experiment (Neuhaus, 1930). Furthermore, an informal survey of the subjects confirmed that there was no apparent motion between the stimuli on the

first and second frames of the prime display itself, but there was always AM between the stimuli on the two-frame target display. Thus, the solution to the prime correspondence problem was realized as a perception of a set of two spatially separated but stationary stimuli presented successively in time. The solution to the target correspondence problem involved the perception of a pair of stimuli on frame 1 that seemed to move to new locations on frame 2. The type of solution to the prime (prior) and target (current) problems, therefore, was qualitatively different. Even with this difference, the results of Experiment VII indicated the existence of a significant priming effect. Thus, the experiment provides at least one situation where a difference in the type of solution adopted for adjacent correspondence problems did not eradicate a prior correspondence effect.

The attainment of a clear picture of the interaction between types of solutions and prior correspondence is made difficult by the fact that there is no standard set of temporal parameters used to define a correspondence problem. Each exposure interval and IFI used to demarcate the length of and separation between frames is completely under the control of the investigator. (The duration of the "psychological moment," if it exists, remains to be determined.) This is most unfortunate, since there is an interaction between types of solutions to correspondence problems and the temporal properties of the correspondence process itself. In fact, it was due to such an interaction that the prior and current correspondence problems yielded different solutions in Experiment VII. The prime problem yielded a motion or a nonmotion solution (percept) as a function of the length of the IFI.

Under some circumstances, and depending on the duration of the psychological moment, a single event or scene (correspondence problem) may itself induce two or more different types of explicit solutions. Consider, for example, the set of correspondence problems provided by an inchworm navigating a concrete sidewalk on the way to an apple tree. If the psychological moment, or "frame" of a correspondence problem is of short duration relative to the speed of movement of the inchworm, then over the course of time of two successive frames and, hence, for a single correspondence problem, the inchworm may not have moved much, if at all. Consequently, the solution to this problem would involve the percept of an apparently stationary inchworm against a stationary background. This type of solution depends on the fact that there was no perceptible spatial displacement of the inchworm between (frames) psychological moments. If the interval of time of a psychological moment was long relative to the speed of movement of the inchworm, then there would be a clearly perceptible spatial displacement of the inchworm from moment one to moment two (i.e., over a correspondence problem). The solution to this problem would involve the perception of a moving inchworm against a stationary background. This is a different type of solution than before in spite of the fact that the dynamics of the stimulus array were not changed. Thus, the duration used to represent a psychological moment may have an important impact on the way an investigator views the correspondence process.

It should also be noted that from the view being presented here every stimulus array, whether static or dynamic, constitutes a problem in correspondence if it is viewed for a duration of at least two

psychological moments. The solution to the problem provided by a static array seems trivial--the same percept will persist from moment to moment. But, it may prove valuable to view such static events as problems in correspondence when the visual system is the subject of investigation.

### Spatio-Temporal Aspects of the Correspondence Process

As indicated in the last section, there is no established or explicitly stated means for delineating individual frames for a set of correspondence problems. In the study of apparent motion, it has been customary to treat as a frame only those time periods when the scene available to the eye contains a spatially nonuniform field. In more common terms, the visual environment must contain one or more objects for there to be a frame of "information." The beginning and end of a frame are denoted, therefore, by the absence of any objects in the field of view. The state where the visual field is blank or devoid of information is generally called an inter-frame-interval (IFI) when it occurs between frames. Frames, according to this view, can vary in (time) length, as can the IFI. For the purpose of the following discussion of the spatio-temporal aspects of the correspondence process, frames and the interval between frames will be defined in accordance with the customary usage of these terms in the AM literature.

In order to appreciate the space-time aspects of the correspondence problem, it is necessary to review more than a single two-frame correspondence problem. For the present study, it is convenient to review the set of frames that constituted one cycle of the MIA paradigm. A

schematic representation of the temporal arrangement of frames for one cycle of the MIA procedure is presented in Figure 23 as a series of time lines. For each time line, the normal state consists of a uniform luminance field. Each deflection in the line represents a frame (*f*). Frame duration is indicated by the length of the deflection interval. The separation between frames, obviously, is the IFI. Individual correspondence problems identified in the reported experiments are labeled. In addition, selected correspondence problems have been annotated by a rectangular box. Each box has been labeled A, B, C, or D, respectively. These labels will be used throughout this section to facilitate the discussion.

It will be recalled that in each experiment frame duration was always set at about 200 msec. IFI varied both within and between experiments; however, for problems A, C, and D, it was always set at about 33 msec.

It should be clear that the hysteresis effect involves the interaction between problems A and C in the first time line. These problems were separated by problem B. Problem B was not evaluated in the present study, hence the dashed box.<sup>4</sup>

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<sup>4</sup>The reader might not have thought of this correspondence problem. But, like the problems investigated in the study, problem B also consisted of two frames separated by an IFI. In the experiments, problem B differed from problems A and C, however, in two ways. First, the IFI was longer by a factor of 15-30. Second, the potential vertical and horizontal AM solutions were the mirror images of those available for either problem A or problem C. Problem B will not be discussed in the paper.

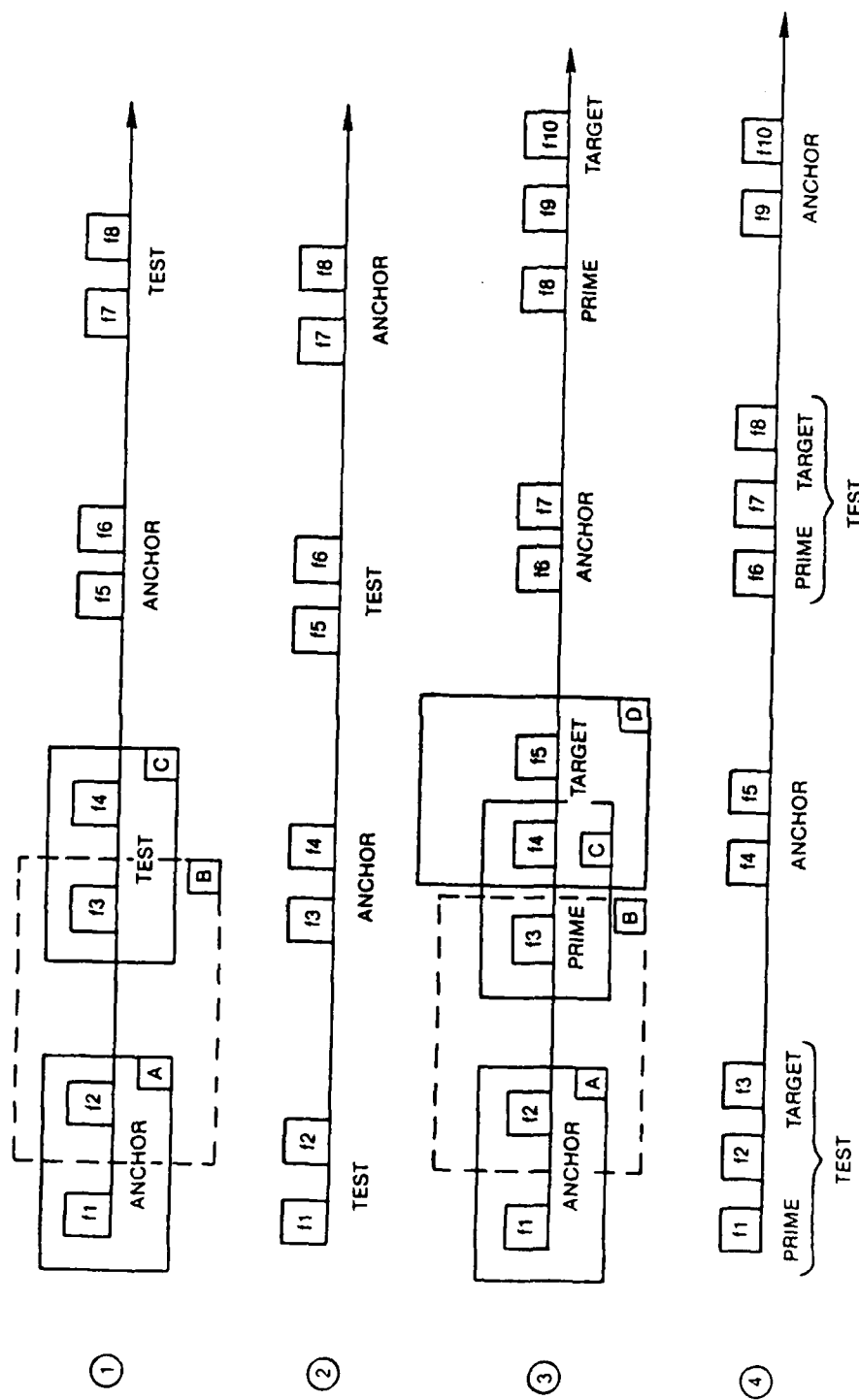


Figure 23. Temporal Sequence of Stimulus Frames (fx)  
Used in Experiments III through VIII

The first thing to note is that problems A and C do not share any frames. This is a defining property of the hysteresis effect. That is, the hysteresis effect involves an interaction between two completely separate correspondence problems.

With regard to spatio-temporal considerations, there was a large difference in the length of the IFI between frames of each independent correspondence problem and the length of the inter-problem-interval (IPI) (i.e., the IFI between frames f2 and f3, Figure 23, time line 1). Since the IPI was under the control of the subject, it was variable in length. Due to equipment limitations, it was always at least 2.5 seconds long. A limited sampling of subject's performance indicated that the IPI was actually probably never less than 5 seconds long and rarely longer than 10 seconds. As indicated earlier, the IFI for each problem was about 33 msec.

The results of Experiments III and IV indicate clearly that a prior correspondence effect can tolerate a rather long IPI. Further, the degree to which a prior correspondence effect was manifest depended upon the particular spatio-temporal parameters of the test display. Thus, it appears that spatio-temporal factors enter into the correspondence process.

As indicated in Figure 23, time line number 3, the priming effect involves the direct interaction between correspondence problems C and D. These two problems are linked both spatially and temporally by virtue of the fact that they share a common frame (see f4 in Figure 23, time line 3). One result of the overlap is that there is no "between

problem" IFI, or in other words, no IPI, as was the case in the hysteresis effect experiments. In short, the concluding frame of problem C was the beginning frame of correspondence problem D.

The IFI immediately prior to the target correspondence problem was varied across the priming effect experiments. The IFI of the prime problem was either about 1 second (Experiment VII) or about 33 msec (Experiments V, VI, and VIII). These values contrast with the 5-10 second IPI that occurred immediately prior to the target problem in the hysteresis effect experiments.

A comparison across experiments indicates that the magnitude of the priming effect was significantly greater than the magnitude of the hysteresis effect, in spite of the fact that the set of target correspondence problems was the same in all of the relevant experiments. One reason for the apparently greater force of the priming effect may be due to the large difference in the length of the IFI/IPI which preceded the target problem. If this temporal variable is the relevant factor, then the data would provide some support for the idea that percept strength dissipates as a function of time.

Both the prime and the target displays were preceded by an anchor correspondence problem in Experiments V through VIII (e.g., see Figure 23, time line 3). The results of Experiment VII evidenced a significant hysteresis effect as well as a significant priming effect. This implies that the anchor display had an impact on the solution to the target correspondence problem. This occurred in spite of the fact that sometimes the solution of the anchor problems were at odds with the

solution of the immediately following prime problem. Temporally, the effect of the anchor problem was separated from the onset of the target problem by about 6.2 to 11.2 seconds. Thus, a prior correspondence effect can be maintained over at least this time period.

It should be clear from Figure 23, time line 3, that the prime display can be viewed as the "current" problem, with the anchor display preceding it in time. Consequently, a prior correspondence effect between the prior anchor problem and the current prime problem can also be evaluated.

Although responses to the prime problem were not collected in the study, there is little doubt that this problem yielded a horizontal AM solution, except in Experiment VII where the solution involved the percept of static but successively presented dots. The important point here is that the same solution to the prime problem occurred within an experiment regardless of whether the prior correspondence problem was the VAM anchor display or the HAM anchor display. This means there was no explicit prior correspondence effect between an anchor display and a prime display. Thus, there seem to be some limitations on the stimulus pattern that evidence a prior correspondence effect.

It will be noticed that four time lines are shown in Figure 23, even though only two were necessary to describe the MIA paradigm as it was used to investigate the hysteresis and priming effects. The additional time lines (lines 2 and 4) merely show the MIA paradigm as if they began with different displays. This is to emphasize the point that a cycle could be defined as beginning with any display. A cycle could

be defined, for example, by a "test" display, followed by an anchor-test-anchor series, just as easily as it could be defined by a series starting with an anchor display. If the present experiments are viewed from the perspective of a test-anchor sequence, a prior correspondence effect during any given MIA cycle would be defined as the impact of one of the five test displays on each anchor display. From Experiment III, it can be seen that the solution to the anchor display problems was essentially always the same and, hence, not susceptible to an explicit prior correspondence effect. This is exactly opposite the result obtained when the test displays were treated as lagging the anchor displays in time.

However, the anchor displays were not always immune from a prior correspondence effect. In spite of the fact that the same anchor displays were used in Experiments III through VIII, in some of these experiments the proportion of responses to the VAM anchor was less than that found in other ones. For example, the proportions of VAM responses were 98.2 percent in Experiment VIII and only 83.3 percent in Experiment VI. The essential difference between Experiments VI and VIII was the addition of four successive vertical anchor presentations per MIA cycle in the latter experiment. Now, if the (last) anchor display is considered to be the current problem that is preceded by some prior correspondence problems, then the change in proportion of VAM responses to the current problem probably was due, at least in part, to an interaction between the spatio-temporal parameters of the sequentially presented prior problems, since this was essentially the only dimension along which the total set of problems differed. In theory then, it may

be possible to induce a prior correspondence effect for any target problem which admits two or more solutions, no matter what the spatio-temporal values of the current problem. One may only need a long enough series of identical biasing prior correspondence problems to make manifest the prior correspondence effect.<sup>5</sup>

#### Percept Strength Model of Correspondence

The  $P_s$  model of correspondence was presented in the last chapter as a means to describe the correspondence process. The model introduced the concept of residual percent strength ( $rP_s$ ) to account for a prior correspondence effect. The essential feature of the model is that the  $rP_s$  for the potential solutions to a prior correspondence problem and the percept strength ( $cP_s$ ) of the potential solutions to a current problem are assumed to be additive, with the additional assumption that

<sup>5</sup>Several of the comparisons in the study were based on data collected in different experiments. There are at least two hazards associated with such a multiple comparison procedure: (1) the confidence interval may actually be less than that stated, and (2) heterogeneity of variance may be such that the subjects in the various experiments do not come from a common population and, thus, the results could be due simply to individual differences between subjects. Theoretically, either or both of these factors could be responsible for the results of the reported experiments. Neither of these factors, however, is believed to be important in the present study. The first factor can be dismissed because in essentially every case where formal statistical analysis was used, the chance probability of occurrence of the significant findings was .001 or greater; therefore, the small inflation of this value that might result from the use of the same data two or three times would still leave the confidence interval well above the normally accepted level of .05. Although it cannot be certain that there was not heterogeneity of variance in all cases where comparisons were made across experiments, in those instances where variance data were collected (e.g., Experiments I and II), there was no evidence that the subjects were drawn from different populations. Thus, given the consistency of results by subject across all of the experiments, it seems most likely that the noted differences between conditions were due to the experimental manipulations performed in the study.

as the time separation between two specific problems is increased, the relative magnitude of the prior correspondence effect (i.e., the strength of  $R^P_S$ ) would be expected to fall off, perhaps because of interference from intervening correspondence problems, or perhaps simply due to disuse.

The results of Experiments I through IV showed the existence of a prior correspondence effect in the form of a hysteresis effect, when a person was confronted with a set of similar correspondence problems. In addition, the data provided clear evidence that the magnitude of the hysteresis effect varied as a function of the space-time characteristics of the test correspondence problem.

The investigation of the priming effect in this chapter also involved a study of the correspondence process. If the  $P_S$  model of correspondence is to be useful, it must also be able to describe the results of the priming effect experiments. Before such a description is attempted, however, it will be valuable to review the constructs of the  $P_S$  model in more detail and to relate them to the local and global structure of a stimulus array.

Basically, there are two constructs in the  $P_S$  model. These are the concepts of percept strength ( $P_S$ ), which was just mentioned, and the concept of a force of correspondence ( $C_f$ ). The  $C_f$  concept refers to the strength of the bond between any element in one stimulus array and any element in a second stimulus array that is processed later in time. Theoretically, each element in the first array can mate with any element in the second array. Thus, there is presumed to be a set of four  $C_f$

values for each two-frame 4-dot correspondence problem. The magnitude of each  $C_f$  is assumed to be a function of the spatio-temporal separation between the mating elements.

The  $P_s$  concept refers to the strength associated with each potential solution to a correspondence problem. As used here, the term "solution" makes reference to the percepts that are supported by the information contained in each two-frame temporal sequence that constitutes a correspondence problem. That is, it is assumed that the stimuli (across frames) will organize into a percept, and that there are several ways this organization can take place. The percept experienced by an observer is taken as the solution to the correspondence problem which has the largest  $P_s$  value. Note, therefore, that  $P_s$  values and percepts are not synonymous terms.

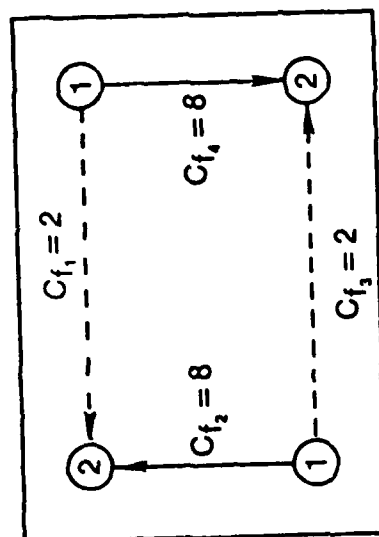
The concepts of  $C_f$  and  $P_s$  are related to the idea of local and global structure in the stimulus array. If it is assumed that the smallest identifiable element of a stimulus array constitutes a local feature, then it is clear that the  $C_f$  concept is concerned with the connectivity of these features as they are processed over time. Hence, the  $C_f$  concept considers the correspondence process at a "local" level of stimulus structure.

The  $P_s$  concept applies to the stimulus structure of a correspondence problem at a more global level of analysis. Furthermore, each potential solution to a correspondence problem can be defined in terms of the relationship among locally-defined stimuli. Thus, each  $P_s$  value represents a measure of the relative strength of a particular

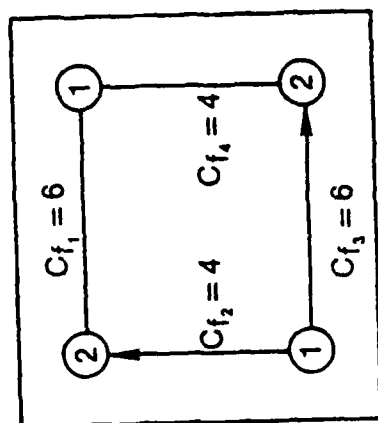
"global pattern" of the local features supported by a two-frame stimulus array. That is,  $P_S$  values are functionally related to  $C_f$  values.

Because of the similarity of global structure across the set of correspondence problems (i.e., anchor and test 4-dot displays) used to demonstrate the hysteresis effect, the resultant prior correspondence effect could be adequately explained in terms of the  $P_S$  model with the use of only the  $P_S$  concept. In other words, there was no need to use the  $C_f$  concept. Since the global structure of the prime and test displays used in Experiments V through VIII were not similar, it is necessary to begin a correspondence analysis with an evaluation of the interaction between locally-defined elements, which brings into play the  $C_f$  concept. Each potential pattern of  $C_f$  values for a two-frame correspondence problem constitutes a particular solution to the problem.  $P_S$  values associated with each solution can, therefore, be derived from the relevant  $C_f$  values. Potential solutions can be formed in the same manner for the displays used to demonstrate the hysteresis effect; thus, both types of correspondence effects can be understood in terms of the constructs of the  $P_S$  model.

To illustrate how the display configurations used to demonstrate the hysteresis effect would be analyzed with the use of the  $C_f$  concept, an analysis of the 4-dot correspondence problems shown in Figure 24 is presented next. The  $C_f$  values shown in Figure 24 were selected arbitrarily and do not necessarily provide an index of the strength of correspondence one would experience with these displays. To make the hysteresis effect clear, both problems in the figure are first evaluated individually. This is followed by an evaluation of problem 2 when it is



PROBLEM 1



PROBLEM 2

Figure 24. Diagram of Two 4-Dot Correspondence Problems ( $C_f$  = Force of Correspondence)

immediately preceded in time by problem 1 and, hence, provides an opportunity for considering a prior correspondence effect.

Problem 1:

$$\begin{aligned} C_f V &= C_{f2} + C_{f4} \\ &= 8 + 8 \\ &= 16 \end{aligned}$$

$$\begin{aligned} C_f H &= C_{f1} + C_{f3} \\ &= 2 + 2 \\ &= 4 \end{aligned}$$

$$\begin{aligned} P_S V &= C_f V - C_f H \\ &= 16 - 4 \\ &= 12 \end{aligned}$$

Since it was established earlier that if  $P_S V > 0$ , then percept  $P = \text{VAM}$ , and if  $P_S V < 0$ , then  $P = \text{HAM}$ , in the above illustration,  $P = \text{VAM}$ . Thus, based on the  $C_f$  concept, the solution to the correspondence problem yields a VAM percept.

Problem 2:

$$\begin{aligned} C_f V &= 4 + 4 \\ &= 8 \end{aligned}$$

$$\begin{aligned} C_f H &= 6 + 6 \\ &= 12 \end{aligned}$$

$$\begin{aligned}
 P_S V &= 8 - 12 \\
 &= -4
 \end{aligned}$$

Therefore,  $P = \text{HAM}$ . Thus, problem 2 itself induces a HAM percept.

The solution to problem 2 changes when it is preceded by problem 1. To wit:

$$\begin{aligned}
 P_{\text{STOT}} &= R P_S (\text{problem 1}) + C P_S (\text{problem 2}) \\
 &= 12 + (-4) \\
 &= 8
 \end{aligned}$$

Therefore,  $P = \text{VAM}$ . Thus, when considered as successive correspondence problems, the problems in Figure 24 illustrate the hysteresis effect.

Note that no attempt was made to reduce the strength of  $R P_S$  even though it is expected to dissipate over time. Such a correction would serve to reduce the magnitude of both  $R P_S$  and the final percept strength,  $P_{\text{STOT}}$ . The dissipation factor would have to be greater than 0.67 before the final percept would change from VAM to HAM.

The extension of the  $P_S$  model to the priming effect is straightforward. For the 6-dot prime-target display used in Experiments V through VIII, the prime correspondence problem contained only a horizontal AM component relevant to the solution set of the target correspondence problem. Therefore, any residual  $P_S$  from the prime display favors a HAM percept over a VAM percept. If  $C_f$  HAM from the prime plus the  $C_f$  HAM from the target is greater than the  $C_f$  VAM generated in the target display itself, then the solution to the target correspondence problem is predicted to induce a HAM percept. This result would

constitute evidence for a priming effect if the same target display would yield a VAM percept when it is presented in isolation. The latter result is predicted to occur when the total  $C_f$  HAM of an isolated display is greater than the total  $C_f$  VAM for that display.

The results of the priming effect experiments are consistent with the  $P_S$  model. Currently available data indicated that the stimuli which are closer in space-time tend to mate in preference to stimuli that are further apart (Kolers, 1972; Ullmann, 1979). Given this as an assumption, the  $C_f$  HAM value produced by the prime display would be lower for Experiment VII than for either Experiment V or VI. Therefore, the  $P_S$  model would predict the magnitude of the horizontal priming effect to be lower in Experiment VII than in the other two experiments. The results are in agreement with the prediction.

In general, the  $P_S$  model provides a reasonable way to conceptualize both the hysteresis effect and the priming effect. Taken together, these effects demonstrate that one cannot adequately assess the way a dynamic visual problem is solved if the investigation is limited to the data contained solely within that problem itself. The  $P_S$  model makes this explicit by describing the relationship between residual and current percept strength.

At present quantitative values cannot be assigned to the magnitudes of  $C_f$  and  $P_S$  for any given correspondence problem. Although the proportion of time a given percept is experienced can be used to index the magnitude of  $P_S$ , and with the proper display configuration the magnitude of  $C_f$ , the proportion of the VAM percepts recorded in the present study

cannot be used for this purpose because of the existence of a prior correspondence effect. To avoid an interaction with a prior correspondence effect, assuming  $P_s$  dissipates, an experiment would have to have widely spaced trials, if several trials were to be given to the same subject. An alternative strategy would be to present a single correspondence problem just once to each member of a large population of subjects. I know of no experiments that investigate the correspondence process which follow either of these strategies. Further research is needed, therefore, to establish quantitatively a scale of  $P_s$  and  $C_f$  magnitudes associated with different stimulus patterns.

#### Other Research

After this dissertation was in progress, the author was fortunate to learn of another research effort directly related to the priming effect. The work was performed by Ramachandran and Anstis (1983). These authors used a 4-dot display as the central portion of a larger 16-dot display. The 4-dot target display was similar to the one used in this study, except the dots were rotated 45 degrees (see Figure 25a). As shown in Figure 25b, this dynamic display supported two AM percepts. Ramachandran and Anstis presented this display under three conditions: (1) 4-dot display alone, (2) 4-dot display embedded in a sequential series of six 2-dot displays (see Figure 25c), and (3) dynamic 4-dot display embedded in a static version of six 2-dot displays.

The purpose of the 2-dot displays was to bias, or prime, AM along the diagonal axis so that one would perceive a "streaming" movement of

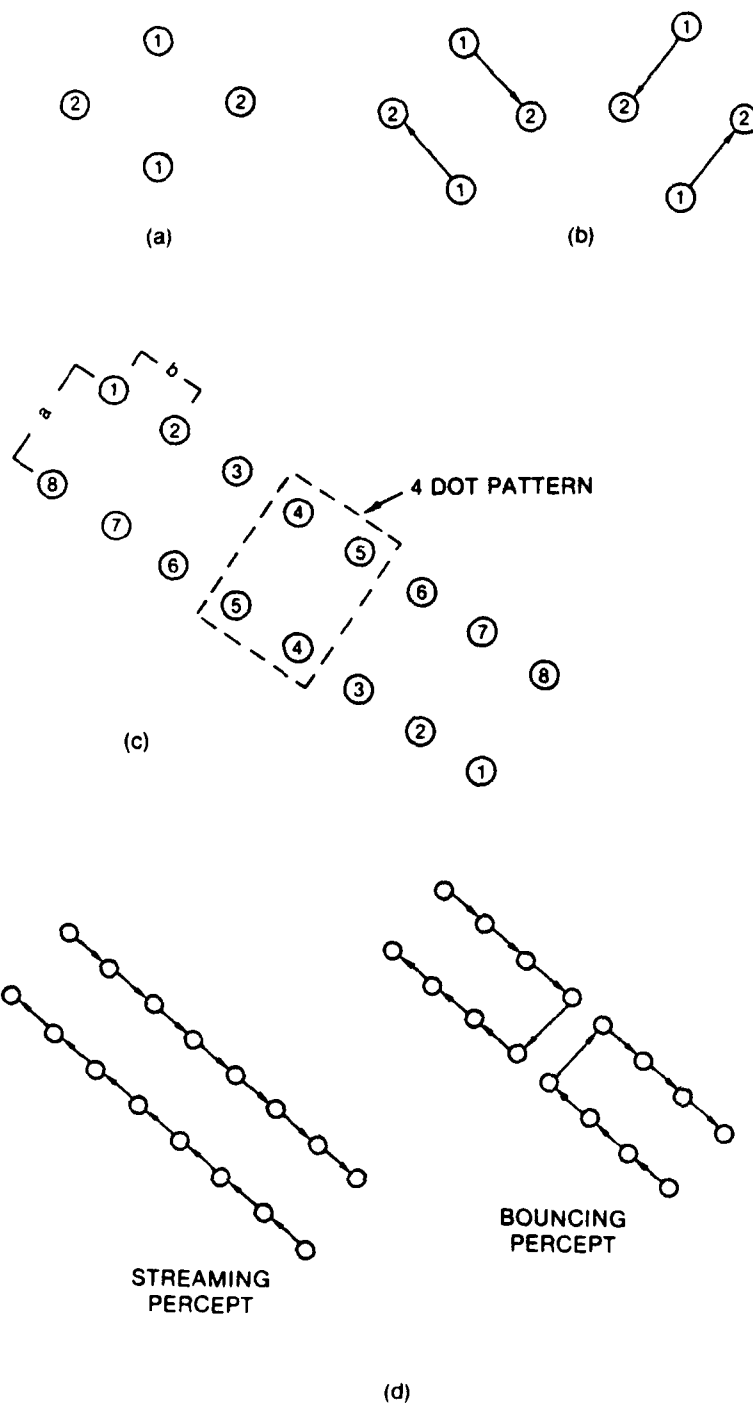


Figure 25. 4-Dot Display Rotated 45 Degrees (a and b) and Embedded in a String of Prime Dots (c and d)

dots in opposite directions along parallel paths. Ramachandran and Anstis varied the distance separating the two rows of dots (distance "a" in Figure 25c) until the "streaming" sensation would just give way to a "bouncing" sensation. A static representation of the stream and bounce percepts is shown in Figure 25d. The "bouncing" percept represented AM along a diagonal rotated 90 degrees with respect to the long axis of the display. The actual "bounce" took place at the site of the embedded 4-dot display. It can be seen from Figure 25 that the manipulation of the distance separating the parallel rows of dots allowed Ramachandran and Anstis to effectively pit the priming effect against a spatial proximity effect.

Four different onset asynchronies were used in their study: 500, 250, 125, and 62.5 msec. In general, the results indicated that the "a" distance between dots had to essentially equal the "b" distance between the dots of the 4-dot display when it was presented alone to yield an equal proportion of streaming and bouncing percepts. With the addition of a static surround, the a/b distance ratio was reduced slightly to achieve the same balance between percepts. A large reduction in the a/b ratio was required to maintain parity of the stream and bounce percepts with the dynamic, prime dot sequence.

Ramachandran and Anstis took these results as evidence that the history of past interactions of dots separated along the parallel rows biased the perception of AM to favor streaming, even when the distance between dots across rows should have favored the bouncing percept. They suggested the priming effect represented a buildup of "visual momentum."

Other than the experiment by Ramachandran and Anstis, there has been little documented empirical investigation of the effects of prior correspondence on the percept formation process. Several researchers, however, have either commented on the apparent influence of prior correspondence, or have at least noted experimental results that can be explained in terms of this concept. Wertheimer may have been the first to report on the influence of prior correspondence in his classical 1912 paper. In one experiment, he used a stimulus pattern composed of a long horizontal line segment and a shorter vertical line segment. One end of the vertical line segment was located at the midpoint of the horizontal line, and the other end was above the horizontal line.

Wertheimer manipulated the tilt of the vertical line toward the horizontal one. When the initial angle of inclination between the right end of the horizontal line and the short line was 30 degrees, and then progressively increased in 10 degree increments, Wertheimer found a rightward rotation phi movement, even when the inclination angle was as large as 160 degrees! Once the inclination angle exceeded 90 degrees, Wertheimer expected phi movement to change to a leftward rotation, since this would involve AM over a shorter distance. That this did not happen surprised Wertheimer, but it would have been predicted on the basis of a hysteresis effect. (It should be noted that inclinations of 100 to 170 degrees induced a leftward rotary phi movement when these angles were used in single exposures of the stimulus pattern.)

Charles Osgood has suggested that: "A final postulate of the Gestalt Theory of perception might be phrased as follows: existing organizations of the field tend to resist modification" (page 206,

1953). Clearly, this is simply another statement of what is meant by the concept of perceptual hysteresis. To support his claim, Osgood took as evidence the difficulty some people have in seeing both the "mother-in-law" and "wife" figures in the ambiguous portrait of a lady introduced to the psychological community by Boring in 1930. Those observers who first perceive the "mother-in-law" are often unable to perceive the "wife" after being instructed to form a new percept (Leeper, 1937). The reverse is also true. Thus, there appears to be a resistance to exchange one stimulus organization for a new one.

Osgood used the Brown and Voth (1937) apparatus to add further weight in support of his suggested postulate of Gestalt Theory. This apparatus consists of four perpendicular arms that meet at the hub of a motorized wheel. A light source was placed on each arm such that its distance could be increased or decreased with respect to the point of intersection of the arms. Also, the distance between the arms could be adjusted. Osgood set the arms of the Brown and Voth apparatus so that they formed an "X" pattern. This effectively placed the lights on the four corners of an imaginary rectangle. The lights on one leg of the "X" were illuminated simultaneously; after a delay, the lights on the other leg of the "X" were illuminated in a like manner. The display, then was essentially the same as the 4-dot display used in the present study.

Osgood (1953) reported that a HAM percept was established when the vertical distance greatly exceeded the horizontal distance between dots and that this percept persisted even when these distance relationships

were reversed in a gradual, stepwise manner. Thus, Osgood's observations are analogous to the empirical results reported in Experiment I and, hence, are compatible with the concept of hysteresis.

Perhaps the most thorough study of the effects of "perceptual set" like phenomena has been reported by Epstein and Dehazo (1961). These investigators attempted to discover the relationship between the roles of expectation and prior experience, and the perception of form. Their idea was to pit expectancy against prior experience such that they would lead to different percepts. Expectancy was established by the instructions to the subject. Prior experience was established by the presentation of a series of identical stimuli prior to a test stimulus. Specifically, the subjects were told that a series of four slides would be presented; the first three slides would be of one figure, A, and the last one would be of a different figure, B. In actual fact, the last figure was always ambiguous and could be perceived as either A or B. Thus, the subjects saw the series: A, A, A, A/B. If expectancy was operative, then the A/B figure should have been perceived as B; if prior experience was operative, then the A/B figure should have been perceived as A. Epstein and Dehazo used the "wife" and "mother-in-law" (Boring, 1930) and the Schafer-Murphy (Schafer and Murphy, 1943) figures as stimulus material. The results indicated that prior experience was dominant over expectancy.

Given their design, prior experience could be viewed as having contained both a frequency component (i.e., number of A's in the prior series) and a recency component (i.e., last A prior to the test stimulus). Both the frequency and recency components lead to the same

prediction: A/B will be perceived as A. Epstein and Dehazo attempted to distinguish between these two aspects of prior experience. In their third experiment, frequency was held constant by alternating stimuli in the prior experience series (e.g., A, B, A, B, A, B). As before, this was followed by an ambiguous (A/B) test stimuli. The results indicated that recency was dominant over frequency. Moreover, the absolute magnitude of the recency effect was essentially the same as the magnitude of the prior experience effect in their first experiment. Thus, it was concluded that the frequency component was of little importance in prior experience.

Epstein and Dehazo obtained the same results (their Experiment III) in favor of the recency hypothesis with (1) the wife/mother-in-law figure, (2) the Schafer-Murphy figure, and (3) the Wertheimer perpendicular line figure described earlier. Thus, the recency effect generalized over the range of simple and complex static ambiguous figures and simple dynamic figures.

In a fourth experiment, Epstein and Dehazo attempted to increase the likelihood that frequency would contribute to the prior experience effect. This was done by varying the number of identical figures in the prior experience sequence. They used three, six, and twelve presentations. Each of these series (e.g., A's) was always followed by a single presentation of a different figure (e.g., B) and then an ambiguous (A/B) figure. The percent of "recent" responses dropped from about 87 percent to about 50 percent as the frequency series length was increased from 3 to 6. The increase from 6 to 12 did not cause any further weakening in the "recent" response rate.

It is instructive to view Epstein and Dehazo's research from the viewpoint of a correspondence process. The stimuli in the "prior experience" series of their experiments could be taken to be anchor stimuli in the MIA paradigm, since they presumably always induced a single, stable percept (e.g., either A or B). The ambiguous test stimulus shared characteristics of both A and B, just like the test targets used in the present study. Consider the designs of their Experiments I, III, and IV in terms of anchors and test stimuli (anchor stimuli will be designated A or B, as appropriate; and test stimuli will be designated A/B).

Experiment I: A, A, A, A/B

Experiment III: A, B, A, B, A, B, A/B

Experiment IV:

1. A, A, A, B, A/B
2. A, A, A, A, A, A, B, A/B
3. A, A, A, A, A, A, A, A, A, A, A, A, B, A/B

Experiment I presents three A anchors immediately prior to a test; therefore, due to relatively strong "A" prior correspondence, A/B will induce an A percept. Experiment III balances the A and B anchors, if they are of equal strength. The last anchor is a B. Thus, somewhat similar to the priming effect, the intervening percept dominates the solution to the subsequent target correspondence problem. Epstein and Dehazo's Experiment IV is similar in some respects to my Experiment VIII. In their experiment, a series of one of the anchors was

presented before both the opposing "anchor" and the "test" stimulus. When this series contained six anchor displays, the influence of the intervening and opposing anchor on the solution to the ambiguous correspondence problem was weakened. No further weakening of the priming-like effect was noted when the series of anchors was extended to twelve. In my Experiment VIII, a series of five anchors did not weaken the prime "anchor" to any noticeable extent. This may be an indication that the relative strength of my prime was stronger than the "prime" used by Epstein and Dehazo.

Both Attneave (1972) and Poston and Stewart (1978) have noticed a hysteresis-like effect with another ambiguous figure like the mother-in-law/wife portrait. This is the man-girl figure devised by Gerald Fisher (1965). Fisher constructed a figure that could be perceived either as a man's face or as a girl sitting on her legs. He made a series of these figures that selectively emphasized the man or the girl according to the amount of "man" or "girl" detail that was included in them. Attneave (1971) noted that when the series of figures was viewed sequentially beginning with one which emphasized the man's face, the man percept would persist and be experienced in those figures where the girl details had been emphasized. The converse was also true when the series began with a figure that heavily emphasized the girl. That is, the girl percept would now be experienced with some of the same ambiguous figures which formerly led to a percept of a man's face. Attneave referred to this resistance to change as hysteresis. Unfortunately, I have found no indication that hysteresis such as this was ever investigated systematically by Attneave or any of his colleagues.

The term hysteresis has been used to describe one property of a cusp catastrophe in the branch of mathematics known as Catastrophe Theory (see Woodcock and Davis, 1978, for a discussion of Catastrophe Theory). Catastrophe Theory is a descriptive mathematical theory that has been developed to formalize the relationships between events which undergo abrupt, discontinuous changes. Any abrupt change from one state to another is called a catastrophe. In terms of the mathematical theory, a change in percept from, say, the "wife" to the "mother-in-law" appears to be a catastrophe. Each of these percepts represent a different state, and the viewer is either in one state or the other. There is no gradual transition from one percept to the other, and the percepts are quite different. The same type of situation exists with the man-girl figure and the 4-dot display.

Poston and Stewart (1978) noticed the catastrophic-like effect perceptual organization seems to undergo at certain times. They used this observation as the basis for the application of Catastrophe Theory to perceptual organization. Poston and Stewart proceeded to use the man-girl figure in the same way it was used by Attneave. They extended the eight versions of the man-girl figure illustrated by Attneave to 24 by varying the total amount of detail contained in each display. Like Attneave, Poston and Stewart noted a hysteresis-like effect; that is, a catastrophic change in percept state when the displays were viewed in sequence. Unfortunately, also like Attneave, Poston and Stewart never performed a systematic investigation of the hysteresis phenomenon.

Ramachandran and Anstis' (1983) research and the demonstrations by Wertheimer (1912) and Osgood (1953) with apparent movement phenomenon

described above here are clearly in agreement with the results of the present experiments. Ramachandran and Anstis interpreted what I have called, in general, a prior correspondence effect, as a phenomenon of visual momentum. Osgood clearly saw the same phenomenon in terms of a question of perceptual organization. Wertheimer simply found it to be an unexplained curiosity. Because motion is involved in every one of the percepts reported by these authors, one is enticed to treat the phenomenon of a resistance to change as an aspect of motion signal analysis.

Given the results reported here, the observations made by Leeper (1935), Rock and Dehazo (1965), Attneave (1971), and others with static stimulus patterns, however, the characteristic of a resistance to change apparently is not limited to a dynamic case.

The "wife" drawing, for example, used to bias or prime one's percept presents a problem in correspondence. Over a normal observation period of several seconds, the visual system must continuously decide if each line in the drawing has remained stationary, changed form, or moved. The solution to the "wife" problem, of course, is that there has been no change in the stimulus array. From the perspective of correspondence theory, the detection of "no change," therefore, is an active process.

The ambiguous version of the wife/mother-in-law portrait provides a new correspondence problem, one that does change in form seemingly in a spontaneous manner. When the ambiguous portrait is preceded in time by the "wife" portrait, it is no longer ambiguous but induces a percept of

a "wife." Thus, there is a resistance to change, and no motion is seen either within or between portraits.

Because the resistance to change can be observed with perceptual problems that do not involve the perception of motion, it is difficult to consider the phenomenon as one which simply involves motion signal analysis. Rather, it would seem to be a property of perceptual organization and, thus, demands a more general analysis of the what-where question. For this reason alone, it seems useful to keep separate the problems of motion detection and the problems of correspondence.

### Chapter III

#### CONCLUSIONS AND FINAL COMMENTS

In this report, the factors involved in the formation of a percept were represented as characteristics of a perceptual correspondence process. This process is believed to yield a percept as its solution to the organization of information extracted from those mechanisms that capture and code visually acquired signals. Further, to maintain continuity across a sequence of percepts, a correspondence must also be established between patterns of information as they change over time. The primary purpose of the present study was to demonstrate the role of prior correspondence in the putative correspondence process. The impact of prior correspondence was consistently and reliably shown in all eight experiments that were undertaken as part of the study. In addition, several other conclusions regarding the correspondence process can be made on the basis of this research. These conclusions are summarized as follows:

1. Prior correspondence can operate in terms of either a hysteresis effect or a priming effect.
2. The magnitude of a prior correspondence effect seems to be related to the spatio-temporal characteristics of a set of sequentially presented correspondence problems.
3. Prior correspondence effects are probably a characteristic of the perceptual process and not a simple response bias.

4. The influence of prior correspondence can be sustained and remain operative even after the intervention of a correspondence problem that is not noticeably affected by prior correspondence; hence, prior correspondence can operate in a telegraphic mode and tolerates or at least infrequent disruption.
5. Recent correspondence problems have more affect on a subsequent target correspondence problem than more frequent but less recent prior correspondence problems.
6. The solution to a current AM correspondence problem can be affected by the solution to a prior correspondence problem that itself does not give rise to an AM percept. That is, a motion percept can be primed by a nonmotion percept.
7. The  $P_s$  Model of Prior Correspondence provides a useful heuristic from which to view and address issues of perceptual organization.
8. The Method of Interleaving Anchors provides a suitable methodology for the scientific investigation of issues of perceptual organization.

This study leaves several questions unanswered regarding the correspondence problem. Although it was shown that the history of prior correspondence was important to the formation of a percept, exactly how long, in both time and the number of presentations, a history of prior correspondence continues to exert its influence is not known. It is

also not clear whether prior correspondence effects simply dissipate with time (disuse) or if dissipation is a function of interference by an intervening problem. The intervention of a similar correspondence problem did not always nullify earlier correspondence effects (see Experiments IV through VIII), but will this be true if the intervening correspondence problem is completely unrelated to both the one immediately before it in time and the one immediately after it in time? Answers to questions like these are needed to advance our understanding of the percept formation process.

In closing, I wish to make some comments on three topics relevant to the correspondence problem. One of these has been addressed, at least tangentially, in the body of the report but the discussion was not developed at that time. The other topics involve a preliminary attempt to put the correspondence problem in perspective. I shall direct my final comments to a brief discussion of: (1) some advantages of treating issues of perceptual organization from the perspective of a correspondence process, (2) the reason for defining the correspondence problem as a question of perception rather than a question of learning and memory, and (3) a function of prior correspondence effect(s) in our everyday perceptual experience.

#### CORRESPONDENCE PROBLEM AND PERCEPTUAL ORGANIZATION

What do we perceive and how does the perceptual process operate? These are two of the traditional questions of psychology. An early answer to the "what" question was that we perceive elemental sensations. But it was not long before Wertheimer and the Gestalt Theory

challenged this answer. The Gestaltists demonstrated quite convincingly that what we perceive, at least in part, are patterns and relationships, and not merely elemental sensations. Patterns and relationships do not seem nearly as tangible as sensations, and they raise the new issues of what are they made and how are they organized. Thus, from patterns and relationships, the question of perceptual organization was born.

In the present paper, the question of perceptual organization has been rephrased as the correspondence problem. The advantage of treating perceptual organization as a problem in correspondence is that it requires the investigator to focus on the what-where issue. One cannot solve a correspondence problem until one knows what is to correspond. The where side of the issue addresses not only the physical location or site of correspondence but also the rules that establish which "thing" corresponds to which other "thing." This what-where concern has often not been made explicit when the problem of perception has been treated as a question of organization. This may be because over the years the concept of perceptual organization has taken on the status of an independent phenomenon; thus, there has been little attention given to its reduction to the more elemental issues of what and where.

When perceptual organization is viewed from the perspective of a problem in correspondence, one discovers that there is probably no single unit or element involved in the organizational process. From previous treatments of motion detection as a problem in correspondence (e.g., Anstis, 1980), it was shown that the unit of correspondence was not fixed. The "thing" involved in correspondence was apparently a sensory attribute at one level of analysis and an "organized" form at a

different level of analysis. Thus, the unit of correspondence at one level is derived from a pattern or relationship among "lower-order" things. It was shown in this study that form objects, as units, correspond to establish a pattern of movement. It is not unlikely that these same form objects are the elements from which the pattern of a scene can be derived. Scenes may then be the elements of correspondence on yet another level of analysis. Outside of the domain of perception, for instance, thoughts could serve as basic elements of correspondence. At higher levels of mental representation, the units of correspondence might then be patterns of thoughts, patterns of patterns of thoughts, and so on. Thus, one outcome of the treatment of perceptual organization as a problem in correspondence is the recognition that the problem occurs at many levels; hence, by implication, it is solved separately at each of these levels. This suggests that it may be valuable to consider perceptual organization as a series of separate problems, perhaps related, each operating on a different level of information processing. Failure to treat the organization problem in this manner may lead to an inadvertent mixing of variables across levels, and thereby make the task of finding lawful relationships a more difficult one.

Epstein and Dehazo (1961) were apparently sensitive to the issue of *mixing variables with regard to the question of "perceptual set" and its impact on perceptual organization*. These authors differentiated set in terms of an expectancy from set as a stimulus-determined variable. Expectancy, such as a response bias error, probably operates at a judgmental level of cognition. Stimulus-determined set is probably more likely to operate at a more perceptual level. Epstein and Dehazo's

study was concerned with set at the perceptual level. The present study could also be viewed as having the same concern at the perceptual level of organization vis-a-vis prior correspondence and the correspondence problem. As it has been shown in the previous chapters, stimulus determined set is affected by space, time, and a prior correspondence variable (either hysteresis or priming). There is no necessary reason to believe, however, that these same variables will have any effect on expectancy-set.

What constitutes a "solution" to a correspondence problem? In my view, the solution is always the discrete percept realized in conscious awareness. Some correspondence problems seem to admit only one solution, while others admit two, three, or even more solutions. How do these types of correspondence problems differ? One might suggest that they differ in terms of the "goodness" of the percepts to which they give rise. If, for example, only one solution is admissible, the percept has a high degree of "goodness." If several solutions are possible, the "goodness" of each of these percepts is less than the case where only one percept can form.

Several psychologists have been concerned over the lack of a quantitative metric of "goodness" of a percept. The best known attempts to qualify goodness have been made by Attneave (1954) and Hochberg and McAlister (1953). Both of these investigators considered goodness of figure to be inversely related to the amount of "information" required to define it relative to any competing organizations. Although both authors demonstrated the efficacy of their respective approach to a measurement of perceptual goodness and an understanding of perceptual

organization, little progress has been made since the 1950s. At present, there is no generally accepted quantitative metric of figural goodness.

In general, figural goodness seems to be related to the probability a particular percept will emerge. In terms of the correspondence problem then, the probability of a given solution to a problem could be equated to the goodness of the induced percept. According to the  $P_S$  Model of Correspondence, each solution to a correspondence problem is indexed by its theoretical magnitude of force of correspondence ( $C_f$ ) and percept strength ( $P_S$ ). As has been shown in the previous chapters, the MIA paradigm provides a way to acquire a quantitative estimate of  $C_f$  and  $P_S$  for each solution to a correspondence problem. Further, since  $P_S$  varies as a function of space, time, and prior correspondence (i.e., the magnitude of residual  $P_S$ ), the "goodness" of a percept can be varied by manipulating these variables; thus, the  $P_S$  concept used in conjunction with the MIA paradigm provides the basis for a quantitative metric of percept goodness.

The issue of percept goodness may be at the root of the paradox that a given perceptual organization may at one time tend to persist (based on prior correspondence) and at another time tend to block its own persistence (i.e., give way to a new percept) (see Osgood, 1953). This paradox can be resolved by the use of the  $P_S$  concept. Consider a correspondence problem that has a solution set of  $n = 2$ . What percept will emerge when  $P_S(A) = P_S(B)$ ? First, since only one percept can be realized in consciousness at any psychological moment, and since at least one percept must always be realized at each moment, one will

always experience either A or B. When  $P_S(A) = P_S(B)$ , either percept is just as likely to be perceived as the other. But, since only one percept can be perceived at a time, there must be some way to bias the solution mechanism to favor one percept over the other. For the perception of visual patterns, there are at least two possible biasing mechanisms. One mechanism is based on the concept of random (neural) noise in the visual apparatus. Because random fluctuations in signal strength are not likely to equally affect both potential percepts, it is reasonable to believe the percept with the larger noise component at each point in time will be perceived. Therefore, given a noisy system, a percept will appear to change from A to B at random without any corresponding change in the input stimulus pattern. Thus, from the viewpoint of an outside observer, the stimulus display appears to induce a multistable percept. If system noise is sufficiently high, the illusion of multistability may also occur when  $P_S(A)$  does not quite equal  $P_S(\text{non-A})$ , so long as  $P_S(A)$  and  $P_S(\text{non-A})$  are in the same neighborhood.

Apparent percept multistability can also result from subtle changes in visual fixation as a stimulus array is under view. This is because retinal anisotropies may differentially influence the capture of visual signals which necessarily affects subsequent information processing. Wertheimer (1912) and Kolars (1972) have both remarked, for instance, that one way to change a percept from one state to another is to simply move your eyes. I have observed the effectiveness of this technique. In fact, one can monitor eye movements and correlate them to state changes in a percept. It is interesting to note that the observer is often unaware of the fact that the percept state change occurred

immediately following an eye movement. The correlation between percept multistability and eye movements, however, has not yet been systematically investigated.

A paradox seemingly occurs when percepts A and B are multistable during one observation period and only one of these percepts, say A, is consistently dominant during a different observation period. That is, the perceptual state changes from multistable to hysteric, without apparent reason or cause. In terms of the  $P_S$  model, hysteresis generally occurs when, say residual,  $rP_S(A)$  is larger than the  $P_S(\text{non-A})$  offered by the next correspondence problem. As indicated by the  $P_S$  model, it is the relationship between  $rP_S$  and  $cP_S$  that establishes whether or not hysteresis will be manifested. The probability that the impact of hysteresis will be felt increases in direct proportion to the magnitude of  $rP_S$ . The probability a multistable percept will occur increases when  $P_S(A) \cong P_S(\text{non-A})$ . Thus, multistability is likely to be manifested when  $P_S$  is nearly in balance across a set of correspondence problems and a steady state percept condition is more likely to prevail when  $P_S$  for completing percepts is well out of balance across sequentially presented problems. Both percept stability and instability, therefore, potentially can be reconciled by the  $P_S$  Model of Correspondence.

In conclusion, the idea that visual perception constitutes a problem in correspondence, one influenced by prior correspondence, may help to clarify what is meant by the terms perceptual organization, percept goodness, and percept stability. Hopefully, it will provide a

useful perspective from which to answer questions covered by these concepts.

#### CORRESPONDENCE PROCESS AND LEARNING

The notion that prior correspondence plays an important part in the solution of a correspondence problem was advanced in this study. Prior correspondence, as the name implies, emphasizes the influence of past events on current ones. Learning operates in much the same fashion through the mechanism of memory. Something one has already learned, for example, can be recalled from memory and used to solve a new problem. The question, then, is: when does prior correspondence (past experience) stop as a characteristic of perception and start to serve as a characteristic of learning? From the perspective of information processing, there is no legitimate answer to this question. Any boundary one may choose to distinguish these terms will be artificial since learning and perception are both the outcome of the processing of information. Learning and perception, then, are in some sense merely a convenient way to partition aspects of information processing. Perception is often viewed to be the lower-level processing of information, while learning constitutes information processing at a higher level, except perhaps when only conditioning is involved. For this reason, I believe it is desirable to treat the correspondence problem as a phenomenon of perception rather than as a phenomenon of learning. This position is based on the fact that the correspondence process appears to be (1) automatic and not under conscious control, (2) always accomplished in a rapid fashion, (3) always completed in each occurrence, and (4) probably insensitive to certain cognitive manipulations. Although

some of these aspects of the correspondence process are also aspects of phenomena often considered to be in the domain of learning, learning phenomena in general are not constrained to be automatic, rapid, or complete in one occurrence.

#### FUNCTION OF PRIOR CORRESPONDENCE: A SPECULATION

If some forms of perceptual set are accepted as statements of prior correspondence, then it can be said that the study of prior correspondence as a characteristic of perceptual organization has enjoyed a long history. Further, even though the process(es) of perceptual organization has/have not been well understood, few would deny that they play an important role in perception. What function does prior experience, vis-a-vis perceptual organization, serve in the every day occurrence of perceiving the physical world?

Although the answer to this question is not known, due in part to our limited understanding of visual coding, prior correspondence effects would seem to be a useful property of any system that performs analog-to-digital conversion, and which needs to sense continuity of output over time. Both of these are characteristics of the human visual system. The retinal mosaic constitutes a two-dimensional array of discrete components, rods and cones, each of which responds independently to the impressed radiant energy. The output from the retina is a set of digitally coded signals that are transmitted through the remainder of the visual system. The end result of these transmissions is an infinite set of discrete representations of the visual environment. Each of these representations is known as a percept, a single,

stable view of the world as we know it. Thus, our conscious visual experience of the world is gained through a concatenation of discrete percepts that change in psychological time.

The human organism, by use of its visual system, must continually decide when each object in the world view has moved, changed altogether, or remained the same. That is, it is always faced with the correspondence problem. Consider the solution to this problem in the absence of a prior correspondence mechanism. For the sake of illustration, I will use the wife/mother-in-law ambiguous stimulus array as the visual scene. It will be recalled that this stimulus array can be perceived as either a young lady (wife) or an older looking lady (mother-in-law). It should be clear by now that without a prior correspondence mechanism, the series of percepts, which would be induced by viewing this stimulus array for some period of time, would be a random ordering of wife and mother-in-law percepts. (The change in one percept to the next may be due, for instance, to small fluctuations in neural noise that bias  $P_s$  to favor one percept over the other.) That is, the perception of the stimulus array would change continuously, even though the visual environment remained the same. Clearly, this represents a confusing, if not chaotic, situation. Indeed, one would pity a poor husband in this situation! There would simply be no continuity in his perceptual environment. During the course of a conversation with his wife, for example, she would change willy-nilly to his mother-in-law, and vice versa.

Prior correspondence adds continuity to our perceptual experience since it serves to increase the stability of each percept over time. If

a percept is a product of both the past percept and the current stimulus array, then small fluctuations in the energy distribution emitted by a physically unvarying stimulus would not be sufficient to cause a discrete change in the experienced percept over a  $t_1, t_2$  time interval. A wife percept would remain stable, for instance, even though the stimulus array at  $t_2$  might by itself induce the mother-in-law percept. Thus, there is no chaos when talking to your wife; she stays to hear the remainder of the conversation. It seems, then, that prior correspondence allows the visual system to handle random distortions and fluctuations in the input signal in a way that does not disrupt the cohesiveness of one's perceptual experience over time. To be sure, changes can be noticed; and they can be quite abrupt, even with the operation of a prior correspondence mechanism. The extent of change must be larger than it otherwise would have to be for the percept to actually change. Naturally, the cost of any system that uses prior information in the solution to an immediate problem is that there is a delay in the experience (percept), and sometimes the experience will be in error. For a stable environment, however, a system with a prior correspondence component is self-correcting and will overcome, in time, the illusory perceptions. Because of this, the gain, in terms of chaos reduction, seems to far outweigh the cost of a momentary error in perceptual analysis that may be induced by the perceptual system.

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